William Street, New York City, while the Underpinning Operations Were at Their Height in 1915

WILEY ENGINEERING SERIES—No. 2

MODERN UNDERPINNING

DEVELOPMENT, METHODS
AND TYPICAL EXAMPLES

BY

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PREFACE

THE authors of this volume, being familiar with the development of the art of underpinning from its rather crude methods in 1900 to its present highly developed state, and having unusual opportunities to gather valuable first-hand material through the generosity of Smith, Hauser & MacIsaac, Inc., whose contract involved the greatest amount of underpinning incidental to any one contract on subway work, have been impelled to make this fund of information available to engineers and contractors.

During the progress of construction on William Street throughout two years, great pains were taken to photograph the essential steps in underpinning, supplementing these with drawings and scientifically altered photographs. It was felt that one good illustration was worth many pages of description, and every effort was made to gather a complete set. Just enough text was added, it is hoped, to sufficiently supplement the illustrations.

As the engineer has usually only a very limited time at his disposal, the book is so arranged that almost without the text he may quickly get correct and accurate ideas as to the proper methods of underpinning.

As the present work of construction on the New York

subways is drawing to a close, it is to be feared that the really wonderful progress made in construction during this period of about sixteen years will be imperfectly recorded and, perhaps, in a large measure lost. This progress was due to the combined efforts of the best contracting and engineering talent to be found in any community. The authors will be sufficiently rewarded if they are the means of preserving the acquired knowledge of only one phase of this gigantic work.

LAZARUS WHITE.
EDMUND ASTLEY PRENTIS, JR.

DECEMBER, 1916.

WILEY ENGINEERING SERIES

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It has been considered advisable to make these books manuals of practice, rather than theoretical discussions of the subjects treated. The theory is fully discussed in text-books, hence the engineer who has previously mastered it there is, as a rule, more interested in the practice. The Wiley Engineering Series therefore will present the most approved practice, with only such theoretical discussion as may be necessary to elucidate such practice.

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MODERN UNDERPINNING

CHAPTER I

GENERAL ASPECTS—UNDERPINNING DEFINED—PAYMENT FOR UNDERPINNING

WHEREVER the foundation of a building or structure is endangered by a neighboring excavation, the need for underpinning arises. Most frequently, the excavation endangering the neighboring structure is that for a new building planned to go deeper than its old neighbor. But the excavation which endangers the largest number of buildings along a street is that for subways or tunnels. Indeed, were it not for the recent developments in underpinning methods, many such subways would not be possible, except, perhaps, at almost prohibitive cost and inconvenience to property-owners.

Methods and costs of underpinning have a vital bearing on many engineering problems, as railroads and tunnels can now be placed close to very costly buildings resting on any kind of foundation, and on almost any material, without seriously endangering them or adding a prohibitive amount to the cost of construction.

In the past many improvements had to be abandoned because of opposition from building owners who feared serious damage to property and business if the excavation incident to such improvements were made. Also many costly locations were substituted for more convenient ones so as to shun the neighborhood of expensive structures.

In many instances in the past buildings have been seriously damaged and the business carried on in them much inconvenienced because of the insufficiency or lack of underpinning or the crude and expensive methods in vogue up to a few years ago. Often large chances had to be taken because no reasonable method of underpinning was known for the difficult cases. The sad experience gained in these instances has caused much opposition, delay, and even defeat of needed improvements which we now know could be safely carried through.

The building of the subways of New York undoubtedly contributed more to the advancement of the art of underpinning than all other causes combined. Almost every conceivable case is here met and solved. Miles of excavations were made close to and much deeper than the adjacent buildings on all kinds of foundations, solid and shelving rocks, earth and quicksand. Some of the buildings had to be carried bodily and set upon the subway roof. The structures varied from unimportant little buildings up to one of twenty-one stories, and included miles of elevated railroads.

The contracts for the construction of the subways up until 1911 did not specifically provide for the underpinning of adjacent buildings, but obligated the contractors to safeguard the buildings, incidentally with the excavation. This worked fairly well, but in many cases led to the assumption of too great risks on the part of the contractors, which was difficult to remedy, as the city did not have authority to order underpinning since there was no item for this in the contract.

In 1911 the form of subway contracts was radically changed from lump sum to unit prices, and underpinning items were introduced into the Lexington Avenue contracts. This gave the engineer the requisite authority to safeguard the buildings by providing specific payment for the same.

The underpinning items for nearly all the contracts are on the front-foot basis, with different items for buildings above a certain number of stories, usually six. It was also attempted to differentiate between underpinning and maintenance, maintenance being an incomplete underpinning or protection of the fronts of buildings by cut-off walls constructed with or in advance of the excavation. This differentiation is a difficult one, and some of the later contracts contain an item for each building or group of buildings likely to be affected by the excavation, the contractor bidding a price including all the necessary work of safeguarding the buildings. This was found to work much better.

On the new subway system the number of linear

feet underpinned was about 75,000 feet. The cost was about $6,350,000. On the William Street subway alone the cost for 3,970 feet of underpinning was about $612,000 Some of the individual buildings are about as follows:

The Woodbridge Building, 100 William Street, fourteen stories, 120 feet front, on fine sand and clay, $25,000.

The Kuhn-Loeb Building, 52 and 54 William Street, twenty-one stories, 69 feet front, on fine clay and sand, $32,000.

The National City Bank, 55 Wall Street, eight stories, 172 feet front, on fine sand and clay, $30,000.

The New York Cotton Exchange, 60 Beaver Street, ten stories, 118 feet front, on fine sand and clay, $24,000.

The usual specifications for underpinning as given in the subway contracts are here abstracted, as they are the only ones of the kind to be found.

"SUBDIVISION 5, SECTION 69. The contractor at the beginning of construction will be required to safely and permanently underpin, and during construction will be required to maintain, protect, and secure such buildings along the line of the railroad as are enumerated in Schedule Item 4-Q.

Underpinning Defined

"By underpinning is meant such method of construction as will transmit the foundation loads directly through the underpinning structure to such lower level

as is necessary to secure the buildings and which will relieve the adjacent ground from improper lateral pressures. The underpinning shall be designed to furnish a safe and permanent support for each independent building. To accomplish this result, the contractor shall use such methods of underpinning, pneumatic or otherwise, as special conditions may require and the engineer shall approve."

" Before the work is proceeded with, the contractor shall submit to the engineer drawings in duplicate indicating the proposed typical and special methods of underpinning."

Payment for Underpinning

"SECTION NO. 70. Payment for safely and permanently underpinning at the beginning of construction and for maintaining, protecting, and securing during construction the buildings enumerated in Schedule Item 4-Q will be made at the prices stipulated in such Schedule Item, which prices shall be deemed to include payment for all work, labor, and material of whatever nature required in connection with safely and permanently underpinning at the beginning of construction and for maintaining, protecting, and securing the entire building or groups of buildings, such as side walls, both interior and along transverse streets; partition walls, both parallel and perpendicular to the building front; interior columns and any other work which may be required, and no allowance will be made therefor

under any other Schedule Item or otherwise. The prices are not to include the payment for underpinning or for maintaining, protecting, and securing vaults, areaways, retaining walls, stoops, or porches, but the payment for such work, when required, shall be deemed to be included in the prices stipulated for excavation in Schedule Items 1 and 2. If ordered by the enginner, the contractor shall dig test pits alongside the building foundations. Payment for such test pits will be made to the contractor as and at the price stipulated in Schedule Item 2-A. (See Section No. 427.)"

CHAPTER II

DEVELOPMENT OF UNDERPINNING AND METHODS

About ten years ago the common method of supporting buildings while neighboring excavations were under way was to employ "shores," which were set up in long, inclined lines against the wall endangered, as shown on Plate No. 1.

This crude method, although usually preventing collapse, often seriously cracked the structure, and large settlements occurred despite the liberal use of screw-jacks at the base of the shores.

Another method much more effective was to use needles, which were horizontal beams carrying the structure, while the neighboring excavation was being made. The needles were inserted in holes or niches cut for them, and were supported on blocking, the load being obtained by the use of wedges or screw-jacks. Later the wall was usually carried on new brick piers containing two wedging stones, which were separated by steel wedges driven home until the piers relieved the needles of their load. This method of needling is much more effective than shoring, but has many drawbacks, as will be shown in another chapter.

When compressed-air caissons were introduced for

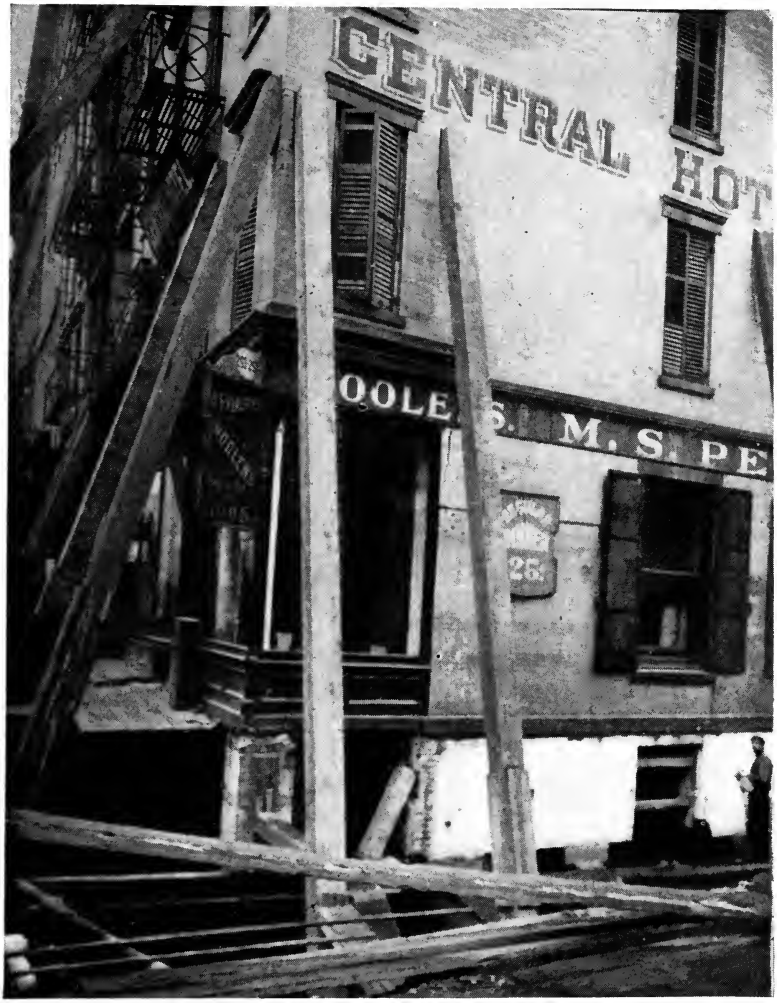

PLATE No. 1. Method of Shoring Used in 1902 during Construction of the Subway in New York City

Note cracks in the brickwork. Compare this with the frontispiece as to street obstruction, etc.

foundations of buildings, a great advance was made. Small, compressed-air cylinders, about three feet in diameter, were introduced for supporting the walls of the neighboring building while the caissons for the new one were being sunk. These small caissons were usually sunk directly underneath the walls to rock or hard-pan, were wedged up and constituted real underpinning. But this method is expensive, requiring the use of compressor plant, air locks, etc., and is not flexible.

The next step was the use of pipes, steel or wrought iron, and filled with concrete, instead of caissons. These were driven or jacked down a suitable depth directly below the wall to be underpinned and constituted a great advance. This improvement was introduced by Jules Breuchaud and J. B. Goldsborough.

In underpinning a building it is often necessary to continue the foundation to a lower level with a new masonry pier, usually of concrete. To excavate for these piers immediately below the foundation was very difficult with ordinary vertical-driven sheeting, owing to the lack of head room. A great forward step was made when horizontal sheeting or well-curbing was introduced by J. C. Meem, for excavation below foundations. Here the boards are placed plank by plank horizontally in pits 4 to 5 feet square. Very little ground is lost and the pits can be sunk almost anywhere, and to any depth, above ground-water level. When the desired depth or ground water is reached,

from within them sectional pipe piles can be conveniently driven to almost any depth if necessary.

Great security and flexibility were obtained when the method of reenforcing and tying together individual foundations by means of steel grillages fastened to their footings and concreted in with them was introduced. This in effect places a new and better foundation for the building to be underpinned and allows almost any desired combination of piers and piles to be used. It often allows the building to be underpinned entirely from the outside, thus saving many costly removals of machinery and much loss of valuable space which previously was thought to be unavoidable.

The use of piles for underpinning has been much facilitated by the introduction of sectional riveted steel and wrought-iron pipe piles, improvements in hydraulic jacks, electric winches for hammer driving, earth augers and miniature orange-peel buckets, etc., described in detail elsewhere.

With the careful methods of sheeting the sides of excavations that are now in use, it is necessary to underpin only those portions of the building that are immediately adjacent to the excavation. In many cases, if the structure is some distance away from the excavation and grade is above water-level, it is not necessary to underpin at all, the method known as protection being used.

This consists of a continuous or semi-continuous

masonry cut-off wall between the excavation and the building footings, as shown in Plate No. 2.

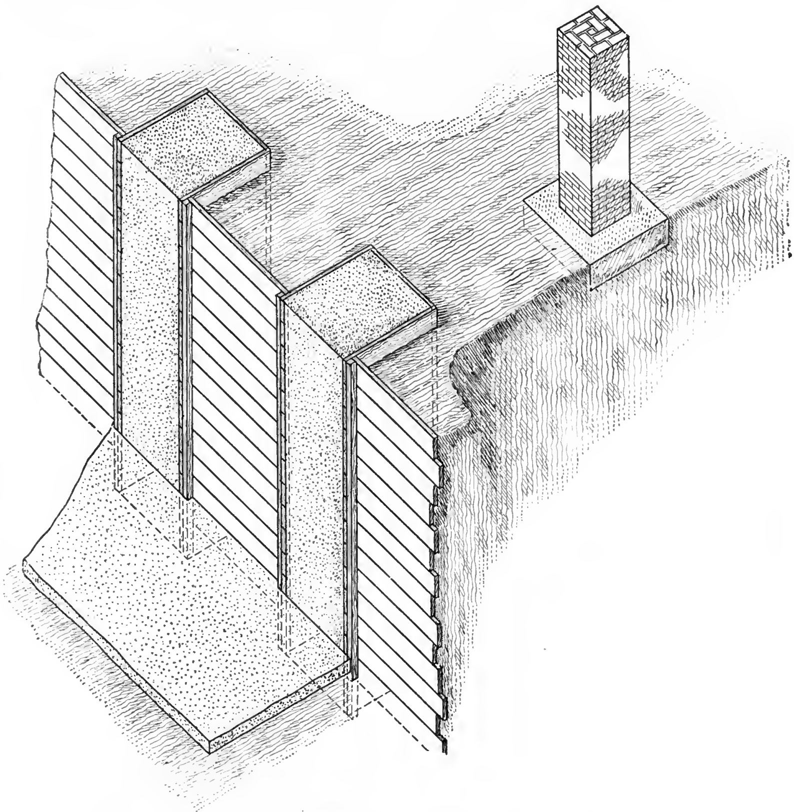

PLATE NO. 2. Method Known as "Protection" Used above Water-level
The building is supported on the original soil, because no ground is lost. The wall is so constructed that when braced it serves as sheeting and cut-off for the trench or excavation

Sometimes a combination of underpinning and protection is used, the underpinning being carried to a one-to-one slope from the bottom of the excavation and a cut-off wall built, as shown on Plate No. 3.

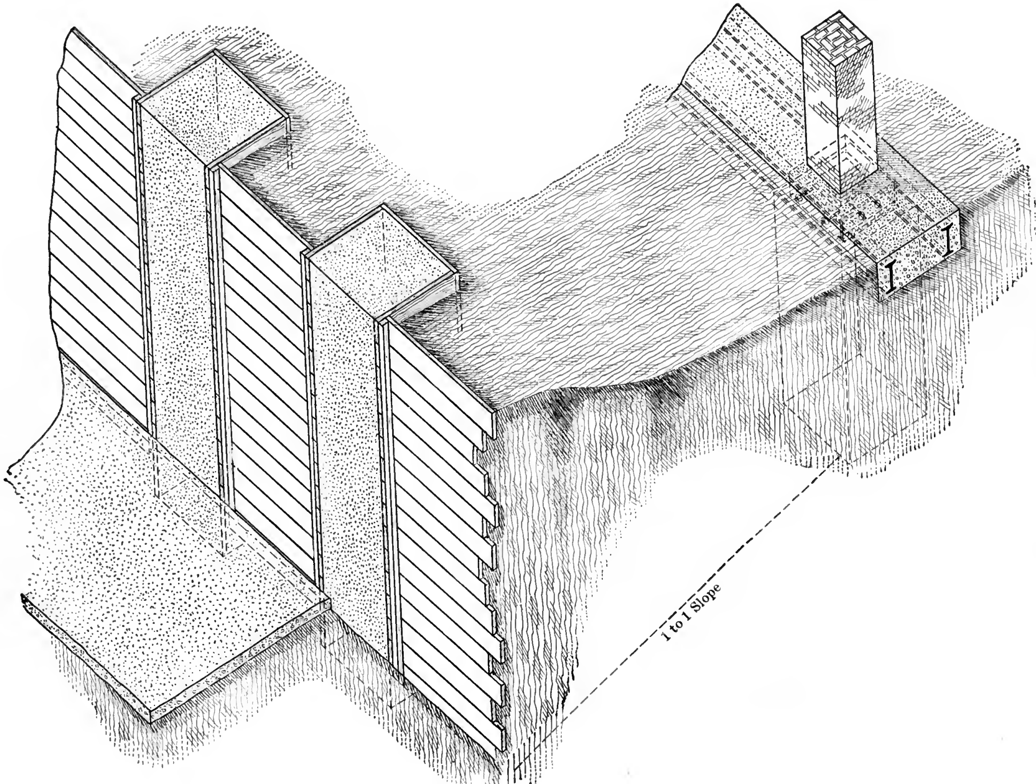

PLATE NO. 3. Combination of "Protection" and Underpinning Methods Used above Water-level
Underpinning piers are carried down to a one to one slope from the bottom of the excavation

It is very important to provide a *tight cut-off* between the building and the excavation, no matter what methods of underpinning are used, in order to protect the interior columns and basements. This becomes of vital importance when the excavation is carried below ground-water level, as then the cut-off walls become impracticable. Tongue and grooved wooden sheeting and various types of interlocking steel sheeting are then employed, depending on the local conditions, and should be driven down sufficiently deep to prevent the soil from boiling up, as is shown in Plate No. 4.

An excellent example of a building completely underpinned by piers placed by means of 4′ x 4′ horizontally sheeted pits is shown on Plate No. 5.

Before underpinning is started a careful examination of the building should be made, particularly in regard to its defects. This is in order to know as closely as may be the condition of the building in case a controversy should arise. The examination should consist of an exact written description and should not consist of photographs only, which would not be conclusive legal evidence.

A good example of the form for such an examination is that employed by the Public Service Commission in New York City in connection with subway construction. The following is an excerpt from one of their examinations:

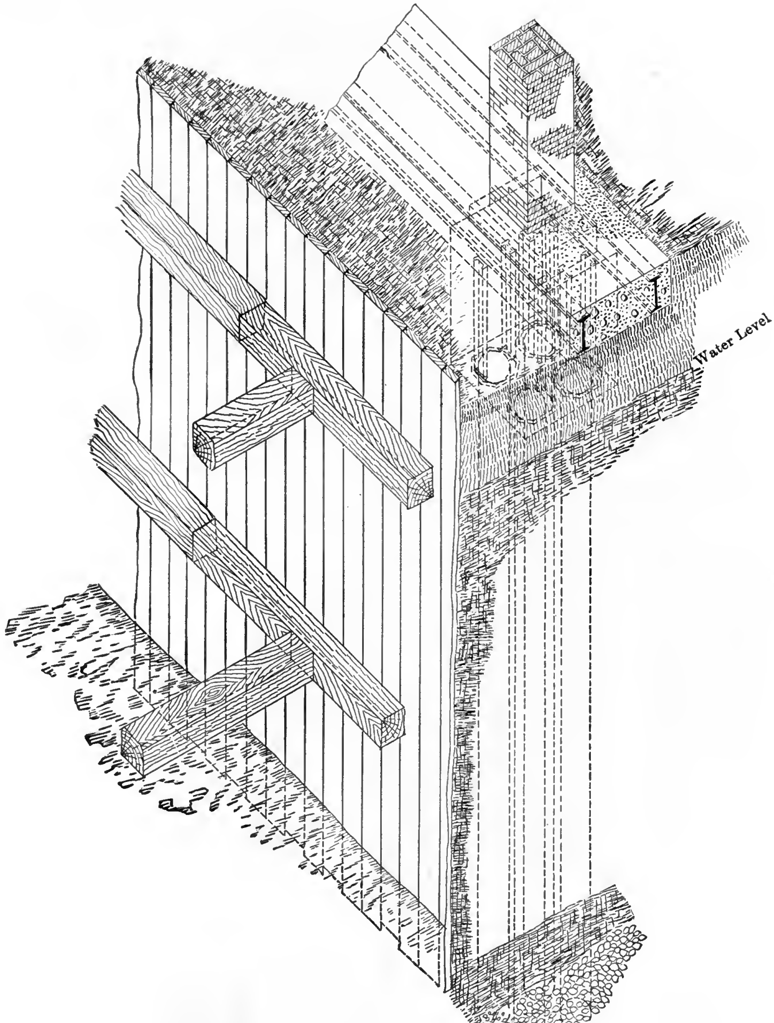

PLATE No. 4. Method of Underpinning below Water-level for a Deep Excavation

Sectional steel concrete piles when wedged to new grillage carry the column loads, the sheeting in front prevents the loss of soil during the excavation, and thus protects the interior walls and columns of the building

Plate No. 5. Building Supported on a Continuous Concrete Wall Built in Four-foot Sections beneath a New Grillage

The wall also acts as sheeting for the excavation, and is twenty-five feet in height

Examination of Building

"Building: 135 William Street, Borough of Manhattan, New York City.

"Description: Sixteen-story granite, brick, and terra-cotta.

"Occupied as: Offices.

"Owner: Royal Baking Powder Co., 135 William Street, New York City.

"Present (representing owners): Mr. M. Feiner, present during examination.

"Present (representing contractors): J. Edward Kloberg.

"Examined by: Harry M. Leon, Jr., Assistant Engineer, per Leo B. Meister, stenographer for Public Service Commission.

"Date: May 17–18, 1915."

EXTERIOR

"*Front Wall on William Street:* First, second, and third stories, granite; fourth to twelfth stories, inclusive, brick; upper stories, terra-cotta.

"*First Story:* Horizontal mortar joints along top and bottom of granite stone along south end of north cellar window need repointing.

"*Second to Fourth Story:* O. K.

"*Fifth Story:* Third window south: lower pane cracked.

"*Sixth to Twelfth Story:* O. K.

"*Thirteenth Story:* A few interior terra-cotta blocks cracked into two pieces.

"*Fourteenth Story:* Fourth window north: fine crack, top of brick panel below sill, two feet from north end, extends vertically downward through middle of one brick, then north along mortar joint one inch, then extends vertically downward along mortar joint on one course of brick, then extends vertically downward through middle of one brick. A few terra-cotta blocks cracked into two pieces.

"*Fifteenth Story:* A few individual terra-cotta blocks cracked into two pieces.

"*Sixteenth Story:* O. K.

"South building line from sidewalk to top of third story shows a maximum 1-inch vertical filled joint. From this point to roof shows ⅛-inch open vertical joint."

The next step is the determination of the loadings of the various columns or walls. These can very often be obtained from the architect's plans, or can be calculated in the usual way. In this connection it might be noted that the allowable floor loadings from the building code of New York City give loads to be provided for, but are more, possibly by 10 or 20 per cent, than the actual loads. In order to give a rough idea of the various column and wall loads that are encountered, it might be said that ordinary 25-foot wide five-story brick and stone buildings have column

loads of 30 to 40 tons at the front wall, and the side walls carrying the floors run about 12 tons to the linear foot at the base. A rough method of calculating the loads on the front wall is to allow 1 to 1½ tons per story per front foot, which may be distributed to the columns according to their distance apart.

The solid masonry office buildings that were built thirty years ago have tremendous column loads, some eight-story buildings having all columns as heavy as 500 tons, of which 90 per cent is actual dead weight, while the modern twenty-story steel skeleton building has also about 500 tons on each column, though it should be borne in mind that each building is a separate problem.

The design of the underpinning is rather simple, but particular care and experience are needed for the actual construction. Generally speaking, underpinning piers are designed so as to give a pressure on the soil of four tons per square foot, while 14-inch steel concrete piles can safely be assigned a load of 30 to 40 tons, testing the piles to 50 per cent more than the assigned load.

CHAPTER III

PRELIMINARY WORK

Shores, Needles, and Foundation Reenforcement

In most cases, before the new foundation or the underpinning proper can be placed beneath the walls or piers endangered by neighboring excavations, it is necessary to place some form of preliminary support. This preliminary support can be divided into three general types—shores, needles, and grillages.

Shores are inclined braces placed against the walls or piers of buildings, and a few years ago were very frequently used, and are effective when applied to light buildings. They can be readily placed in niches cut in the brickwork, the lower ends resting on screw-jacks, used to tighten up the shores and to take up settlement. They usually consist of long 12 x 12 timbers, which can be readily shown to be very weak as columns and as placed are decidedly lacking in lateral stiffness. They have to be very numerous to support any considerable load and are usually very much in the way. Formerly, when no better method was known, they frequently blocked streets and sidewalks. When compared with other devices they are an expensive and cumbersome way of supporting buildings. An example of shoring is shown on Plate No. 6.

In the case of a building burned out by a fire, shores may be useful to prevent the collapse of dangerous walls while they are being torn down, and they may also be useful to support light walls in the altera-

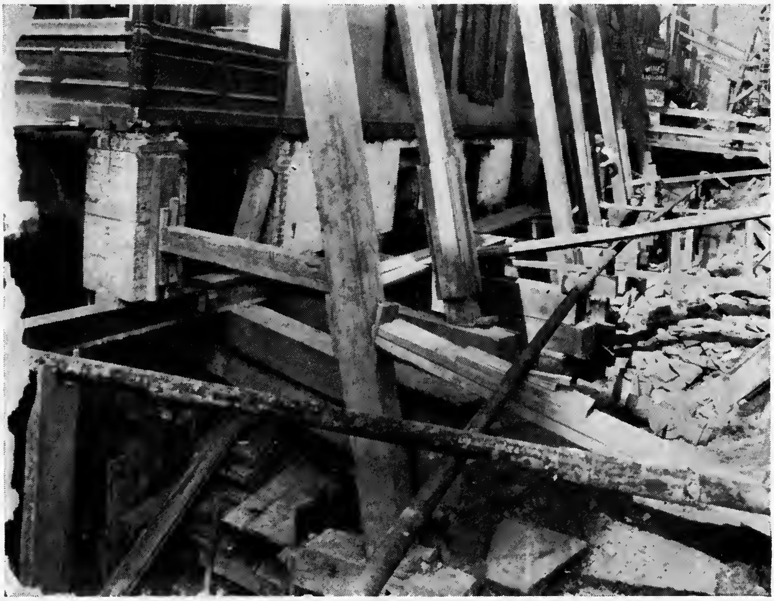

PLATE No. 6. Shores Used in 1902 during the Construction of Subway, New York City
Note total removal of sidewalk. Compare with modern methods

tion of building fronts, although in this case vertical posts supporting short horizontal beams previously set in holes in the walls or columns are more usual. In a few instances shores may be used to advantage in connection with other means to counteract the tendency of the building to move horizontally or to give a remote support at the beginning of the regular underpinning

operations. For heavy buildings, composite timber and steel shores have been used to good advantage, the foot of the shore resting on a concrete block and the top in a niche in the masonry; steel wedges driven home will transfer as much of the load as is desirable to the shores, or screw-jacks may be used. In general, steel wedges in underpinning operations are much to be preferred to screw-jacks. They give greater stability and can hardly overload the member or unduly strain or rack the building as jacks have repeatedly done. In the effort to take up settlement jacks have often taken up too much and cracked the building.

A good example of a shore is shown on Plate No. 7, though this took a very minor part in the operations.

The second method of preliminary support is that where needles are used in the place of shores. Needles are vastly more effective and adaptable than shores, and very many ingenious systems of needling have been employed in underpinning operations.

In general, they are horizontal beams, usually steel I-beams, so placed as to relieve the foundations of a wall or pier of its load and to transmit the loads to temporary blocking or piling on either side of the wall or pier, allowing space for removing the old foundation and substituting a new one. Knowing the load and span, the size of the beams is readily computed. Where the walls are to be supported by needles, holes are cut at intervals through the wall and the needles inserted at convenient intervals after the walls are re-

enforced by small I-beams or stones bricked in to take and distribute the bearing from the beam and to prevent rupture of the wall.

Where isolated columns or piers are to be supported the common practice is to cut niches into the columns

PLATE NO. 7. Composite Steel and Timber Shore
Steel channels are rigidly bolted to timber separator and wedged to foundation and concrete abutment

fitting the I-beams. This sometimes weakens the masonry pier, so that it is advisable rather to fasten a clamp or bracket to the column. This can readily be done by timber or steel clamps bolted fast or a concrete collar can readily be cast to the column after a few dowels and a little reenforcement have been placed.

Clamps for supporting cast-iron and steel columns have to be very carefully made, particularly where heavy concentrations have to be carried. Steel columns are more readily fastened to as rivets may be removed and the holes used for bolting clamps or brackets to them. Usually these brackets are heavy channels fastened with a sufficient number of bolts to provide the necessary shearing strength.

Cast-iron columns are the most difficult to fasten to. A good method is to drill clear through them and insert long steel pins to prevent the clamps from slipping on the column. Several clamps may be used, each bearing on one or more pins. Great rigidity can be secured by concreting in the clamps; this is well illustrated by Plate No. 8.

The greatest difficulty with needles is to provide a sufficient bearing area, for their abutments or supports. It is usually necessary to occupy considerable space in the interior of the building for the inner supports, which is often difficult to obtain, and may necessitate the moving of much machinery, etc. Again, the exterior ends of the needles may project over an excavation, necessitating the building up of a great height of cribbing or the driving of groups of piles with platforms to provide exterior abutments for the needles. To overcome this difficulty, in one instance, the needles were used as true levers, the fulcrum being near the building and the projecting ends counterweighted to balance the wall loads, but this does not appear to be good practice.

PLATE No. 8. Clamp on Square Cast-Iron Column of 250 Tons Load before Being Concreted in
The timber members are 12″ x 12″ oak. Note the steel pins in holes bored through the column

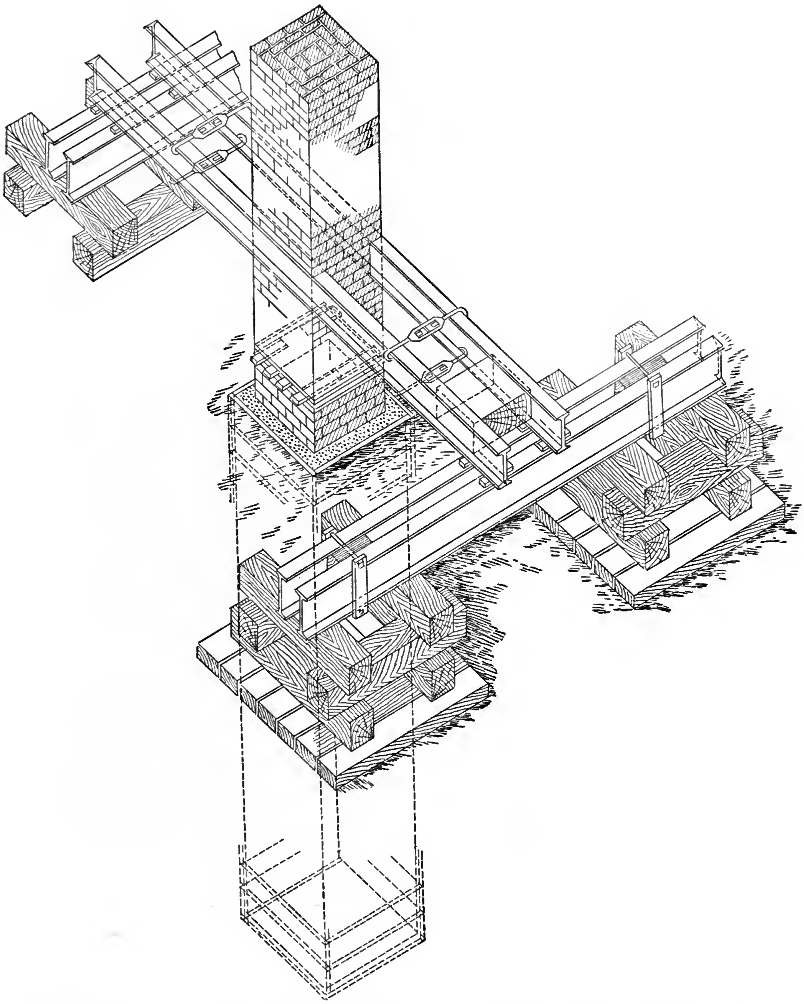

Plate No. 9. Typical Needling Method Showing Underpinning Pier and Wedging

Needles are designed to support the column while new foundation is placed below

An effective and safe method of needling a building front is to place long beams parallel to the front, both inside and outside, with pairs of transverse needle beams resting on them, each pair carrying a column. The longitudinal beams are carried on blocking and the needles wedged from them to take the load. This method is well shown on Plate No. 9.

A very heavy system of needling is shown on Plate No. 10. Here the subway passes directly under a heavy ten-story building whose cast-iron columns carried loads up to 250 tons, sub-grade being 20 feet below the column footings. As previously explained, heavy brackets were fastened to the columns, the brackets bearing against transverse 20-inch I-beams carried by heavy pairs of 15-inch H-beams. These H-beams were reenforced by 12-inch I-beams grouted in between them, making a very stiff unit, as shown in Plate No. 11, being broad and low with no tendency to overturn. It is of course not economically designed as regards the steel used, but it is nevertheless very cheap because the members are not drilled or cut and can easily be placed in position, easily dismantled, and the steel recovered in perfect condition. The needles were carried on heavy timber towers, from which they were wedged. No jacks were used in the transferring of the load to the needles, the wrought-iron wedges proving very efficient.

Although needles give an effective preliminary support, enabling new foundations to be placed, they

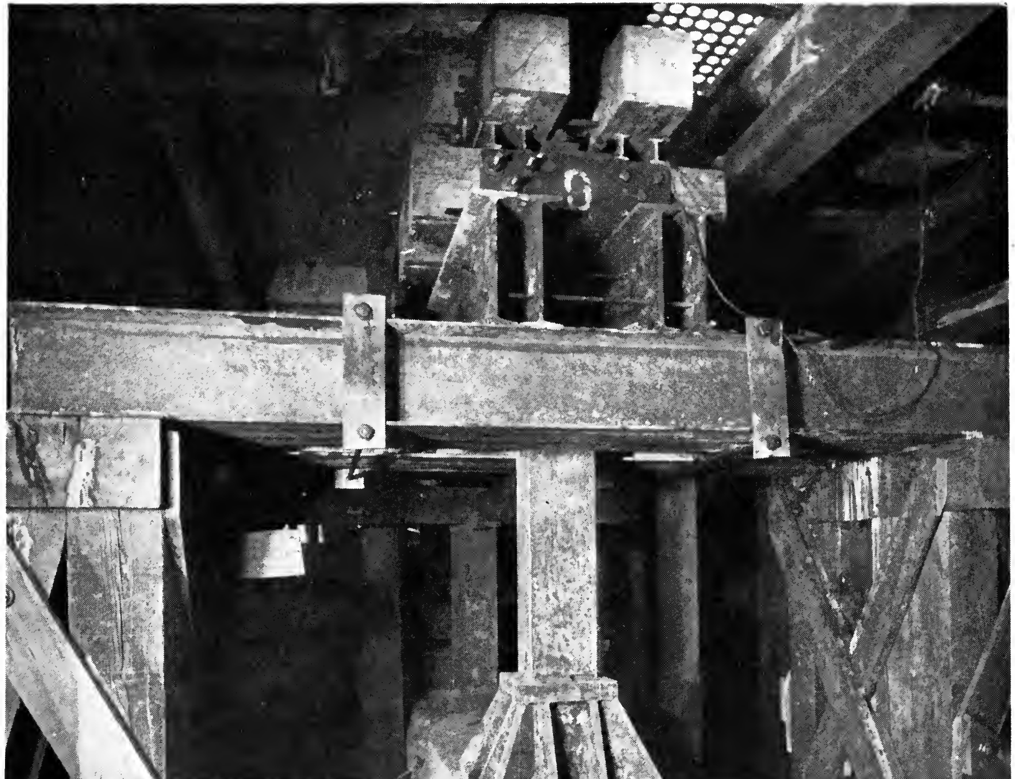

PLATE No. 10. Method of Needling 250-Ton Cast-Iron Columns. Detail of column clamp shown on Plate No. 8. Note timber towers, with oak caps, and composite needle-beams as shown on Plate No. 11

have many disadvantages, and their disadvantages multiply rapidly and become very serious when heavy loads have to be carried. Where the loads are over 200 tons, the needles become very heavy and it is

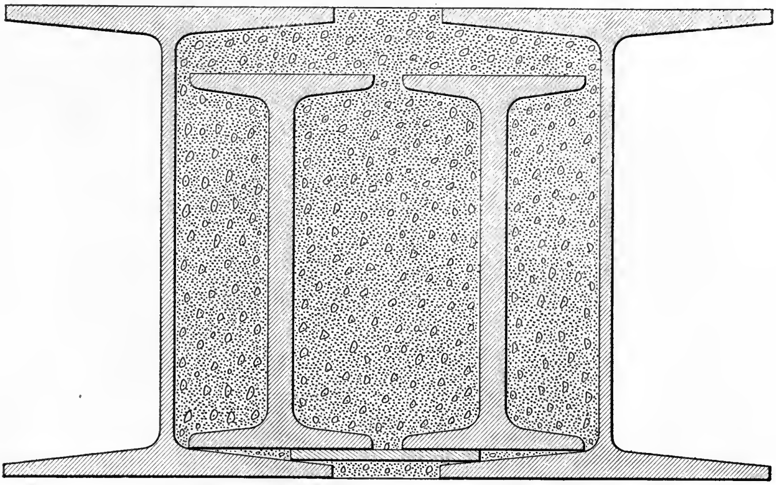

PLATE No. 11. Showing Cross-Section of Needle-Beams Composed of 15″ H-Beams and 12″ I-Beams

This construction saved much steel detailing and proved very rigid and stable

difficult to secure sufficient area for the necessary cribbing and blocking which serve as abutments for the needles, the bearing being usually figured at about 2 tons per square foot. These abutments and the needles themselves will often be seriously in the way of the occupants of the building and those engaged on the construction alongside the building. When the column loads run as high as 500 tons the size of the needles may become enormous and a sufficient bearing

area for the blocking practically impossible. The disadvantages of needling buildings have been apparent for a long time, but it has only been within the last few years that better methods of preliminary support have come into use, and with them the danger of a serious collapse has with careful work almost disappeared.

In brief, these new methods take the foundation and support of the buildings as they are and, instead of removing them before placing new foundations or underpinning, add to them and strengthen them so as to allow the new supports to be more freely placed below them. The foundation so reenforced is brought up to the standard of a scientific and properly designed footing of the continuous grillage type—for instance, that of a building on a continuous mat of concrete reenforced by steel I-beams or rods. Often, buildings are on isolated footings of I-beam grillages which can readily be made continuous by filling the gap between them with similar construction.

Exposure of a great many foundations of all types along the New York subways clearly shows that the best type of footings for buildings, with the exception of caissons or steel concrete piles, is that of the grillage, composed of two layers of I-beams *thoroughly* embedded in concrete, provided a sufficient bearing area on the soil was originally allowed. These grillages or footings may be isolated for individual columns or connected along the exterior walls. There seems to be an im-

pression, and it is given considerable emphasis in some text-books, that isolated footings proportioned to the load are much safer than continuous footings, which of necessity cannot be uniformly loaded per square foot of bearing area. There may have been some justification for this when masonry without steel reenforcements was used, as then cracking of the foundations was feared and could be mathematically demonstrated. But, with a foundation properly reenforced, there is practically no danger of cracking, the continuous foundation being vastly superior to the isolated one. Even in the case of old masonry foundation laid up in lime mortar, very little cracking of foundations was observed when on a yielding sand.

A good type of foundation on earth is one whose footings underneath the exterior walls consist of a continuous mat of I-beams and concrete with a generous bearing area, say 4 tons per square foot, so constructed as not to encroach on the street or neighboring property. The interior foundations may be isolated mats of I-beams and concrete, or, better, a continuous mat between columns.

Such a building is easily underpinned and will not suffer much from neighboring excavations; it may be underpinned with concrete piers or piles placed directly beneath the footings, and little disturbance or inconvenience to the occupants of the building will be felt if the underpinning operations are in competent hands.

Where a building has not the ideal type of founda-

tion for underpinning purposes, the aim should be to add to it sufficiently to approach the ideal. This can be well illustrated by the Woodbridge Building.

This building, a thirteen-story structure, approached very closely to the subway structure, necessitating the underpinning of its front wall, carried by eight columns, each loaded with about 435 tons. Each column was founded upon a grillage consisting of two layers of I-beams, the lower one paralleling the building front. These grillages approached within three or four feet of each other. To diminish the risks of underpinning an additional grillage was decided upon, although it was considered quite feasible to underpin each grillage individually, as they were of generous proportions.

First the I-beams were well stripped of their enveloping concrete, exposing the sides of the outside I-beams of the upper row and the ends of the lower row as shown on Plate 12. Next holes were drilled in the concrete between the beams for a great number of hooked dowels which were grouted in. Then 1½-inch rods were cut to fit the spaces of the upper row of I-beams. Rods were also placed in the gaps of the lower row, their ends being supported by short rods wedged between the I-beams, and inclined rods were butted against the upper flanges of the upper I-beams. The cutting of the rods was easily accomplished with the acetylene torch. A form was set up and all the steel thoroughly embedded in a generous block of rich concrete. This grillage took

Plate No. 12. Reenforcing Rods Placed for the Grillage in the Woodbridge Building, 100 William Street
The column loads are about 435 tons each

about 3½ tons of steel rods and 70 cubic yards of concrete and, although generous in size and strength, was economical as to cost. It is believed to be the first

PLATE NO. 13. Original Footing of One of the Columns of the Kuhn-Loeb Building, 52–54 William Street
Below upper beams is another layer of I-beams, then 30″ of foundation concrete resting on fine sand

heavy underpinning grillage built entirely of steel rods and concrete.

The heaviest grillage built for underpinning purposes is probably that of the Kuhn-Loeb Building, a modern twenty-one-story steel structure with column loads of over 500 tons each. The front wall of this building is carried by five columns supported by I-beam

grillages about 17 feet below curb level, and founded on a very fine-grained sand three feet above water level. The grillages encroached about six feet upon the street and the future subway structure, and the building was so underpinned as to allow the cutting off of these encroachments.

The two columns at the south end rested upon a huge "cantilever" girder, in turn resting upon a transverse layer of 18-inch I-beams. The other columns of the front row were founded upon a layer of 20-inch I-beams resting upon a transverse layer of 15-inch I-beams, which in turn were founded upon a 30-inch layer of concrete. This structure is clearly shown on Plate 13.

The grillage beams were carefully stripped of concrete. Some of them were found to be badly rusted where hot water from a boiler had penetrated the somewhat porous enveloping concrete. This carries the lesson that grillage beams should be thoroughly enveloped in concrete (a dense mortar is best).

To make the layers of I-beams continuous, beams were cut with an acetylene torch to closely fit between the outside of the webs of the lower layer and others to overlap the ends of the upper layer. In addition hooked dowels and reenforcing rods were used to strengthen the outward projection of the grillage. To spread the column loads directly over the reenforced grillage, buttresses were built outward from the steel columns, which were stripped for the purpose. The resulting grillage, shown on Plate No. 14, was strong

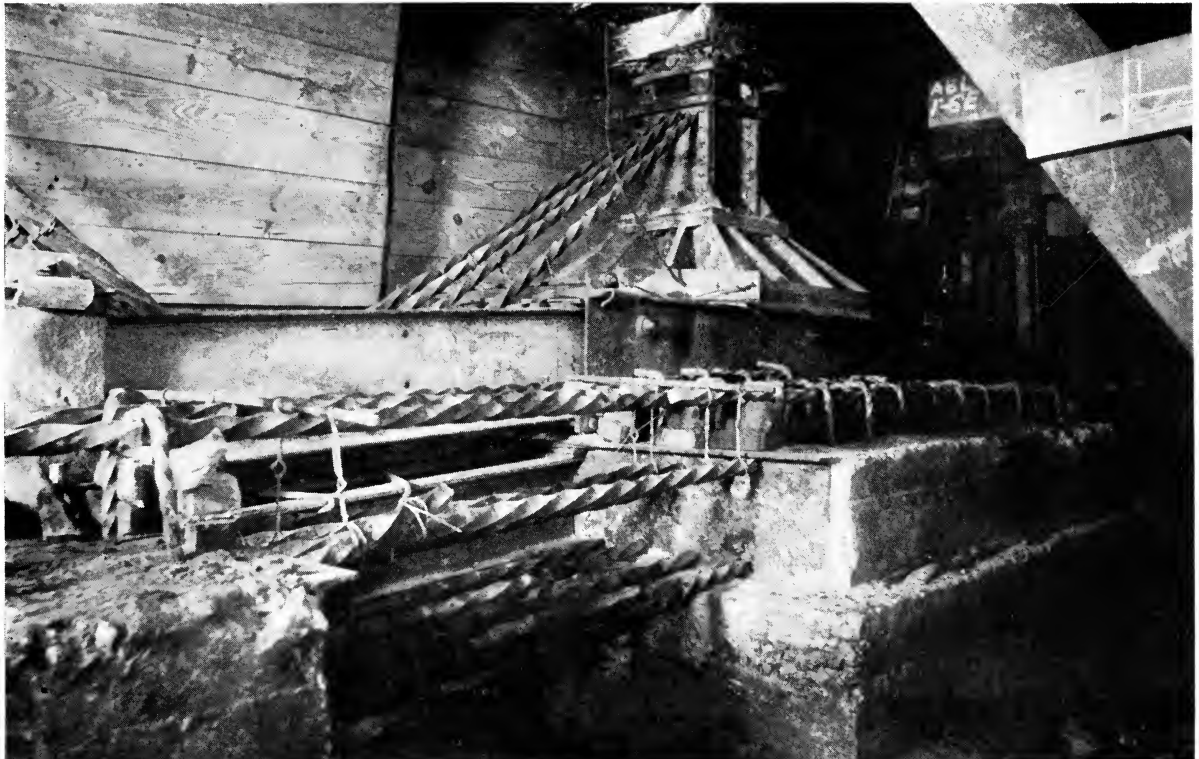

PLATE NO. 14. Reenforcing Steel and I-Beams in the Grillage for the Twenty-one-Story Kuhn-Loeb Building before Concreting

enough to fully take the upward thrust from the new steel underpinning piles which were subsequently placed. These reactions are very considerable, as a group of five in a 4 x 4 foot area may be much above

Plate No. 15. The Grillage of the Kuhn-Loeb Building after Concreting with Underpinning Piers Marked Out and Numbered
View is from same position as Plate No. 14

200 tons. The entire structure was concreted in with a mixture rich in mortar, as shown on Plate 15. The additional steel used was 8½ tons; additional concrete 55 cubic yards.

There is always some uncertainty as to just where to place the reenforcing steel of an underpinning grillage. Some contend for the lower portion, others the upper,

and each or both are logical, depending upon what theory of the shifting of the column loads during underpinning operations is adopted. If the underpinning is first placed between the columns and securely wedged and the columns settle slightly, the grillage will be in tension on the upper side, which is probably the normal case. Because of unequal settlements and continuity, the stresses may be reversed, and thus it was thought best to reenforce top and bottom to take care of all contingencies. The safest guide appears to be a good sense of proportion and the placing of the additional steel so as to make up for defects in the original footing and to thoroughly piece them out.

Just previous to the introduction of steel frames to buildings, columns were commonly carried on heavy piers or pyramids of brickwork. By cutting niches into those to be underpinned, inserting heavy crossed I-beams and concreting them in, the piers may be connected rigidly, as shown on Plate No. 16, and then are readily underpinned. An older type of foundation, and one which gives excellent results, is the continuous masonry wall laid up in a trench. Often these walls, though adequate for their purpose, are not sufficiently strong to stand the stresses of underpinning operations. By scraping out their joints, inserting dowels and longitudinal reenforcing rods or beams, and concreting them in with a rich mixture, the walls are readily reenforced, as in the case of the Bank of New York, shown on Plate No. 17.

Plate No. 16. Crossed I-Beams between Brick Piers
The beams were placed in niches carefully cut for them and then securely concreted in

Plate No. 17. Reenforcement of Dowels and Rods
Used for reenforcing wall laid up in lime-mortar and subsequently concreted in. Bank of New York

The commonest buildings underpinned are those of five or six stories with isolated piers and carrying comparatively small loads, 20 to 40 tons. As they are often poorly built, they are the more easily injured

PLATE No. 18. Grillage Detail for Brick Pier of Typical Small Building Showing Beams and Dowels

When surrounded by concrete this is a very effective and rigid construction

and often give more concern than heavy structures. The piers or footings for these buildings are readily connected by employing small I-beams and dowels, fastened front and back as shown on Plates No. 18, 19 and 20. After being concreted they spread the load over a much larger area and tie the footings together securely, and are then readily underpinned.

Lattice girders have been extensively used for grillages. They have the advantages of being continuous and readily connected together in tight places. Such a use of a lattice girder at 123 William Street

PLATE No. 19. Typical Steel Grillage for Small Building, Showing Beams, Cross-Ties, Dowels, etc., before Concreting
Appearance after concreting shown in Plate No. 20

is shown on Plate No. 21. Here the interior girder was placed under a barber-shop floor which was tunneled under and supported by I-beam props. The advantages of the lattice girder have been largely lost since the acetylene torch for cutting steel has come into extensive use. With an assortment of

PLATE No. 20. Typical Grillage for Small Building after Concreting, Showing Small Pipes Left for Grouting the Underpinning Piers

View from same position as Plate No. 19

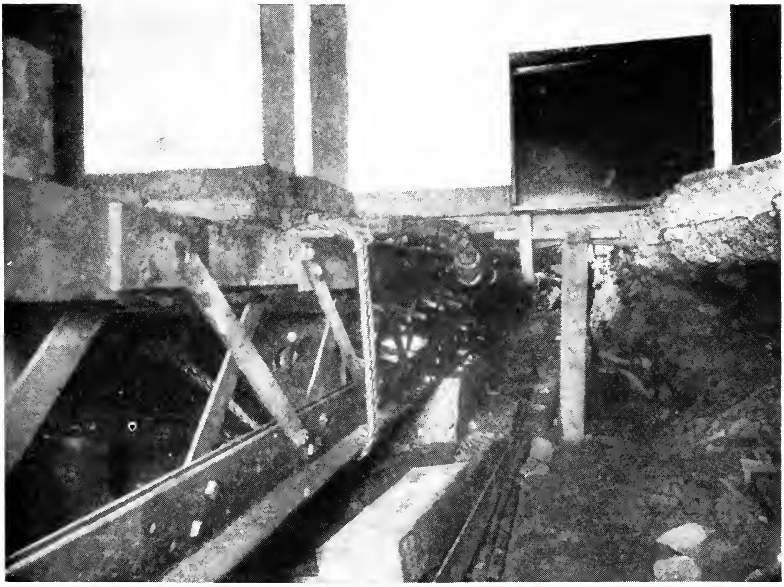

PLATE No. 21. Showing the Use of Lattice Girders for Grillage Purposes before Concreting

Lattice girders are useful when space is too small to place long beams

I-beams and rods a grillage can readily be made to suit almost any condition, the beams, rods, dowels, etc., being cut to length as actually found to be needed when the foundation is stripped. When the Kuhn-Loeb grillage was being made up, a torch, set up adjacent to the work, was kept continuously in use for days cutting up the steel to the desired length.

The function of dowels in steel concrete grillages for underpinning is very important. They develop great strength, not through their actual shearing strength, which may not figure very high, but by keeping the concrete gripped to the old masonry and thereby developing a tremendous friction grip.

CHAPTER IV

UNDERPINNING PIERS, PILES, AND WEDGING

PITS for the new underpinning piers can sometimes be sunk by the old-fashioned vertical-driven sheeting with which we are all familiar, but cannot be used where there is scant head room. This method has now been almost entirely supplanted by the horizontal well-curbing method, which was referred to in a previous chapter.

By this method pits can be made almost any size up to 12 feet square, but are usually 4 or 5 feet, and have been sunk 60 feet through sand and clay, using only 2-inch sheeting. The most conveniently sized plank to use is 2 x 8 inches, and as the work must be done with considerable nicety in order not to lose ground, it is advisable to use plank finished on all four sides. A skilled gang of workmen will sink about 6 feet per shift of eight hours in sandy ground clear of boulders, though sometimes as much as 15 feet have been sunk, sinking always stopping at water-level, when other methods must be resorted to.

Unless the pit is under a needled column, when pit sinking can be started directly, it is necessary to dig carefully in underneath the foundation the necessary distance, putting in temporary piles or posts

where needed to make up for the lost bearing area, and to carefully sheet the sides of the excavation, packing behind the boards with soil where necessary.

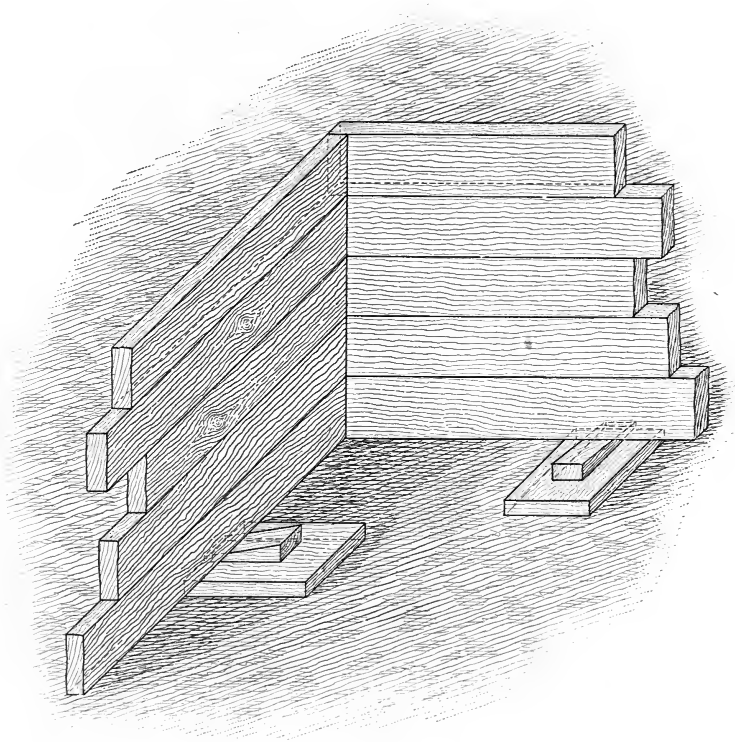

PLATE No. 22. Shows Method of Placing Foot Block and Wedges to Hold Bottom Boards in Underpinning Pit Until Set Is Complete

Enough ground is then dug out to place a set of horizontal planks, which are each in turn carefully packed and hammered into place, being temporarily held until the set is complete, by a foot block and wedge, as shown on Plates Nos. 22, 23, and 24.

When the pit has been sunk the required depth, it is concreted to within two feet, or other convenient

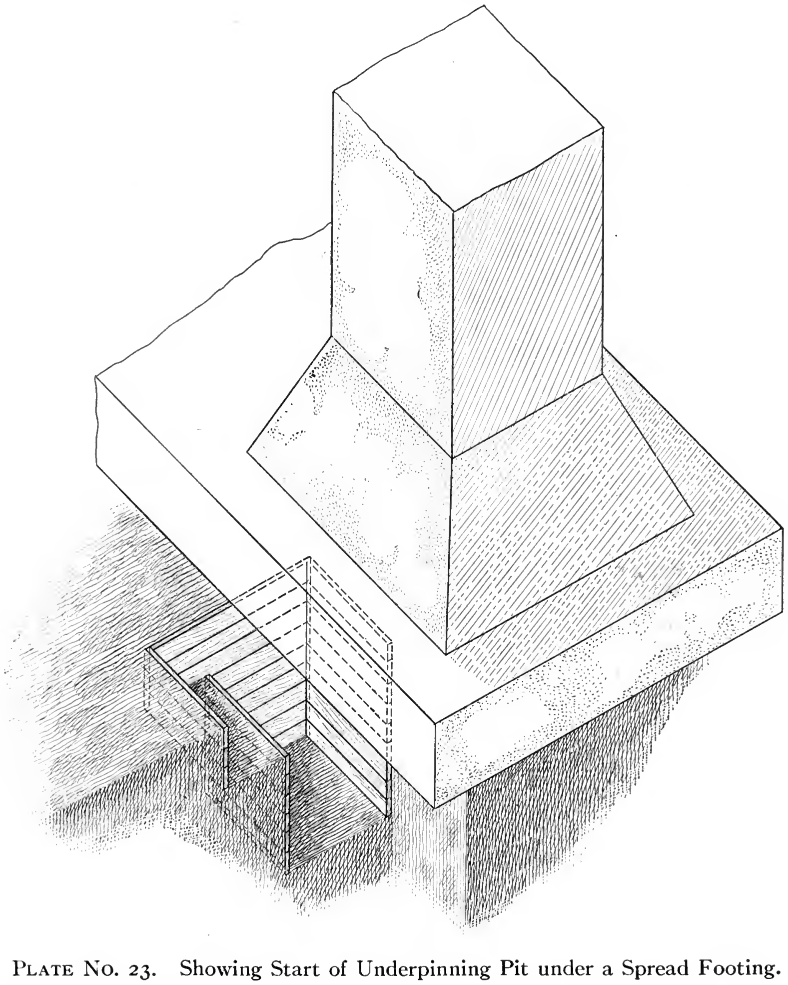

PLATE No. 23. Showing Start of Underpinning Pit under a Spread Footing. Only small fraction of original bearing area is lost during this operation. New foundation to be placed in pit is wedged up before another pit is started.

working distance, from the bottom of the foundation, and allowed to set. Then it is wedged up. This

important operation, which conveys the load of the column to the pier, is sometimes done by means of a small masonry pier and wedging stones, or, better, by the use of steel I-beams and wrought-iron wedges,

PLATE No. 24. Showing Start of Underpinning Pit under Spread Footing. Crossed 15″ I-beams are embedded in concrete between brick piers
Pit is for the purpose of providing space and head room to drive and wedge piles to foundation

the whole concreted and carefully grouted up, as shown on Plate No. 25.

In case the bearing area of the pit is insufficient, or in case it is necessary to go below ground-water level, the pier is supplemented with sectional steel-pipe piles. These are driven by a dropping weight or a

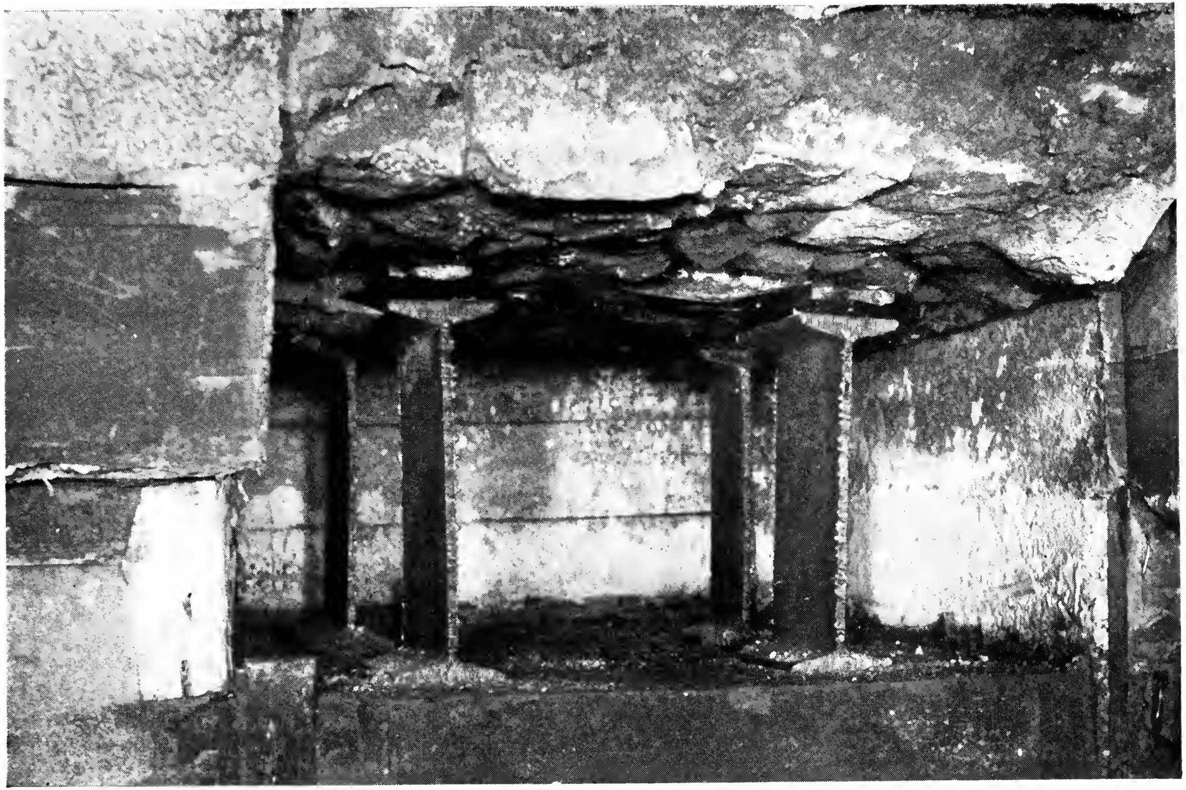

PLATE NO. 25. Method of Transferring Column Load from Old Foundation or New Grillage to New Underpinning, Concrete Pier (4′ x 4′ Square) with Short I-Beams and Wrought-iron Wedges

hammer if sufficient head room is available, or by hydraulic rams.

The pipes while being driven are mucked out every foot or two to make the driving easier and to prevent the pipe from buckling, and when driven are concreted, tested, wedged up directly to the foundation or grillage, if possible, and the pit concreted and carefully grouted.

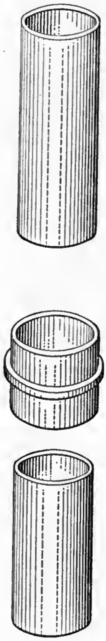

PLATE No. 26. Sleeve for Connecting Sections of Steel Pipe Used as Piles

The sectional pile pipe used, generally 12-inch or 14-inch in diameter, is of various kinds. Ordinary wrought-iron pipe with cast-iron or steel couplings is very satisfactory, but perhaps expensive unless the pipe is obtained second-hand. This is shown on Plate No. 26.

An equally satisfactory pipe, and one which is more easily handled, is the sheet-steel, lap-riveted pipe. This comes in any desired length, usually 2 feet. With a thickness of only $\frac{7}{64}$ inch, surprising strength is obtained, an empty pipe having withstood a load of 90 tons without rupture, though 50 tons is a more usual load. The starter or first length of the pile is usually reenforced with an extra thickness of metal to prevent the buckling of the cutting edge, as shown on Plate No. 27.

A gang can drive and muck about twenty feet of pile in ground without boulders in eight hours with

Plate No. 27. A Good Type of Riveted Steel Pipe for Underpinning Purposes
The sections shown are one and two feet long, 12″ and 14″ diameters, and are follower and starter sections

a drop-hammer rig. This consists of a "nigger-head" winch, a few snatch blocks, a graphite lubricated hemp rope and a hammer about 9 inches diameter and 400 or 500 pounds weight dropping 2 or 3

PLATE No. 28. Pile-Hammering Rig
Piles were driven a few feet at a time and then mucked out

feet on to a steel pile cap and guided by hand, as shown on Plate No. 28.

When the necessary head room for hammering is not available, a hydraulic ram is used. The best rig for this purpose is an independent pump good for about 13,000 pounds per square inch with a ⅝-inch plunger, so that two men can easily pump, and a 4½-inch diam-

eter ram about 20 inches high, the available extension being about 11 inches and the weight about 175 pounds. The ram is connected to the pump by ¼-inch flexible copper tubing with steel fittings. This copper pipe should be annealed from time to time to destroy the crystallization which comes from constant bending and which would result in a break. This whole rig is very light, and is easily portable by a gang which can drive and muck from 4 to 25 feet per eight hours with a general average of 8 feet for ground without boulders. This apparatus is shown on Plate No. 29.

The mucking is accomplished by means of earth augers and miniature orange-peel buckets. The augers are attached to a muck stick of ¾-inch pipe cut into lengths of about 4 feet, with a universal joint for each section so that it can be conveniently handled in a restricted space. The orange-peel bucket is attached to the same muck-stick so that it can be pressed against the soil while the closing rope is pulled, or a new type of bucket can be used, which is operated very conveniently by means of two ropes, the lowering one being attached to a 12-pound ball which acts as a hammer to drive the open prongs of the bucket into the soil before the closing rope is pulled. The mucking implements are shown on Plate No. 30. When the soil is fine-grained a piece of leather riveted to the upper blades of the earth auger is a big help to prevent the muck from slipping between the space between the

Plate No. 29. Jacking Rig, Consisting of Hydraulic Pump, Flexible Copper Pipe, and 4½″ and 6″ Diameter Hydraulic Rams. Normal hydraulic pressure, 6,000 pounds per square inch, but apparatus is good for 13,000 pounds per square inch pressure

upper and lower blades, by acting as a clap valve. Water-jetting or blowing out the muck from piles is a quick and efficient method if piles are being driven in the open, but in the vicinity of buildings is likely

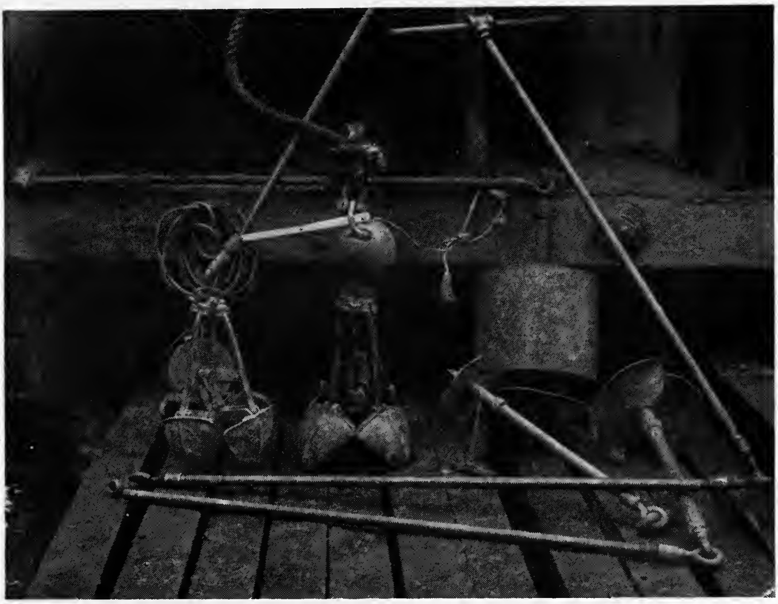

PLATE NO. 30. Pile-Mucking Implements
Augers with jointed rods commonly used. Small orange-peel buckets useful for heavy sand and gravel, especially when operated by winch

to cause trouble by removing too much material from the pile and causing a flow of the soil, and consequently a settlement of the structure. Care must always be taken not to muck below the bottom of the pile, for, although the pile may drive easier, lost ground may result.

Piles up to 30 feet in length are conveniently

driven, and when they are driven as deep as it is necessary to go, they are concreted. This has to be done with a great deal of care because the water in the pile will wash out the cement, leaving merely sand and gravel in the pile. The best way is to bail or pump the water out of the pile and then concrete. If this is impossible or unsafe, for sometimes the removal of the water causes the soil to rise in the pile, a bottom-dumping bucket is used. When the pile is concreted it is next tested.

This means that the concreted piles are jacked down until they give a predetermined resistance of 40, 60, or 80 tons, or more, measured by means of a pressure gauge on the pump. They are then wedged up, providing the pit is not too deep, in which case the pit is concreted and the concrete wedged as before described.

When the pile is wedged directly, a cap, generally a short length of steel channel, is placed on top of the pile and from it an I-beam is wedged with wrought-iron wedges (usually ½ x 2½ x 16 inches) against the bottom of the foundation by driving in the wedges hard with an eight-pound hammer.

In this way a load of about 8 tons can be immediately transmitted to the pile. If the pile is to carry from 30 to 40 tons, the usual load of 12- or 14-inch piles, it is now known that there must be a further settlement of the foundation before this load can be sustained. Furthermore, we have found by a series of careful experiments, one of the results of which is given in the

accompanying curves shown on Plate No. 31, that a pile, not on rock, will repeatedly settle with repeated applications of the load. This is due not only to the elasticity of the pile itself, but mainly to the fact that the bulb of pressure which forms at the base of the pile (and the shape of which has been developed by J. F. Greathead) has to be reformed by further penetration after it is destroyed by the release of the load.

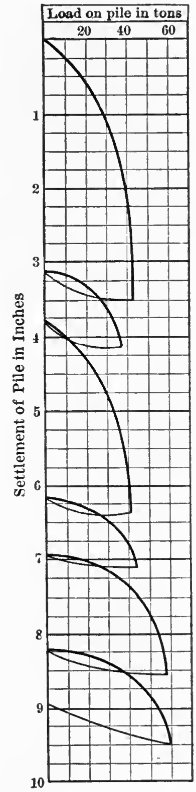

PLATE No. 31. Pile Settlement Curve

Note rebound and settlement after each loading of pile

To overcome this difficulty, piles are now wedged up without releasing the load, by a new method for which a patent has been applied for by one of the authors. When the pile has been tested to refusal at the predetermined test load without releasing the load, two pieces of I-beams are cut to fit and are wedged up one on each side of the jack which rests on a special pile cap. When the wedging is completed the jack is released. By this means, 40 tons can be immediately transmitted to the pile, as has often been proven with a strain gauge. This method will reduce the settlement of a structure materially and is shown on Plate No. 32.

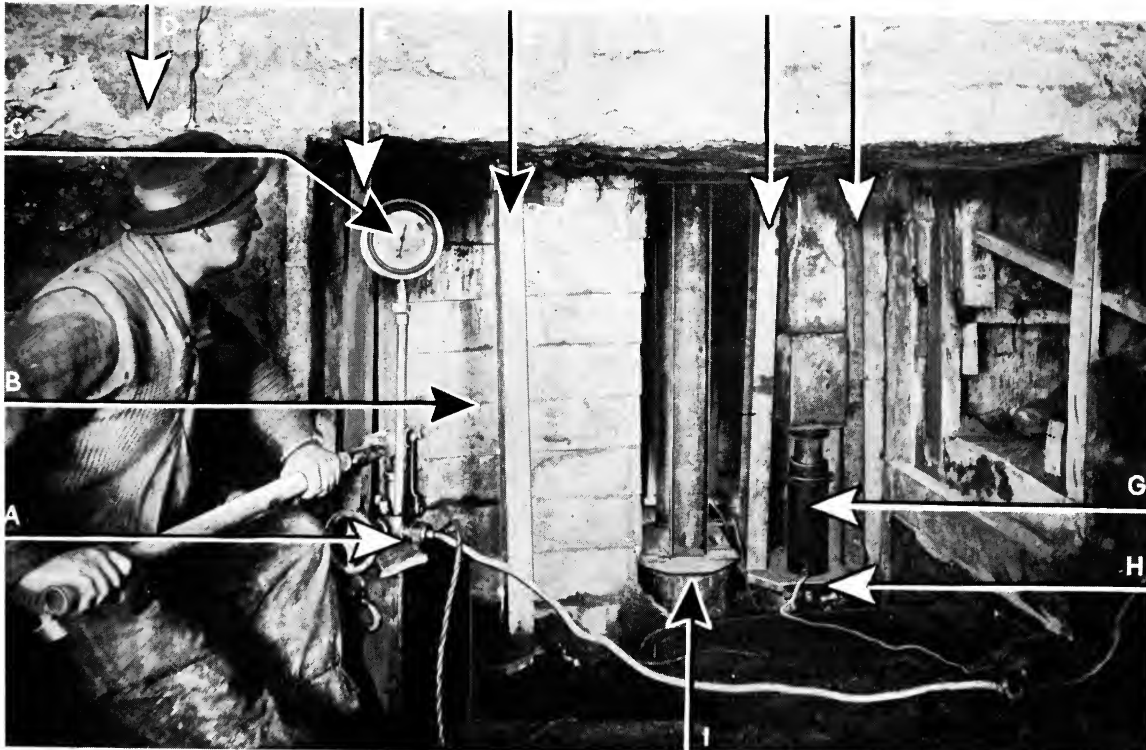

PLATE NO. 32. Improved Method of Loading Piles Beneath Building Foundations, Patents Pending

A, Hydraulic pump; B, Concrete encasing piles previously wedged; C, Hydraulic pressure gauge; D, Original spread foundation; E, I-beams on pile previously wedged; F, I-beams being wedged; G, Hydraulic jack; H, Special pile cap; I, Pile completely wedged

An indispensable adjunct in underpinning operations is an apparatus for cutting iron and steel by means of a flame. This consists of a torch connected by means of two flexible armored hoses to tanks of

PLATE No. 33. Burning Apparatus in Operation
Portable rig found to be very useful

compressed oxygen and a rich hydrocarbon gas, a picture of which is here shown. The two-wheel go-cart for hauling the apparatus around is very convenient, especially if a central spindle with a ring at the top is added so that it can be hoisted by a derrick-hook when necessary. In most communities such a wheeled apparatus, which is now widely used for welding, can readily be rented for a reasonable price. It is shown on Plate No. 33.

CHAPTER V

SPECIFIC EXAMPLES OF UNDERPINNING

146, 148, and 150 William Street

THESE buildings are of the ordinary five-story brick type with isolated columns, the loads running from 20 to 30 tons each. The excavation line was the building line of the building and sub-grade about 16 feet below the foundations. This arrangement precluded the use of a reenforcing grillage because it would physically interfere with the future subway, so needling was resorted to.

Two continuous beds of 6 x 12 timbers 4 feet long were placed on the soil, a fine-grained sand, 4 feet from the front and 4 feet from the rear of each column, and two 18-inch longitudinal I-beams were placed on each bed. Needles of 15-inch I-beams on top of the 18-inch I-beams were then placed one by one in niches carefully cut in the brick columns to receive them. The needles of each column were then lashed together to prevent spreading and were wedged on the longitudinal I-beams until they relieved the footing stones of the columns of their loads. The lower parts of the columns were then cut away, and pits sunk on the line of the future excavation directly under each column. This work is shown on Plates No. 9 and No. 34.

The pits were sunk about 18 inches below grade; a toe was dug out 18 inches to help prevent overturning and was reenforced with steel rods; then the pit

PLATE NO. 34. Showing Exterior Longitudinal 18″ I-Beams and 15″ I-Beam Needles with Lashings to Prevent Spreading
An effective form of needling where there is room to place them and where the loads are moderate

concreted. When the concrete had set a brick pier was built up to the original column, two ⅜-inch steel plates, or wedging stones, with wrought-iron wedges between them, being inserted at a convenient height. When the mortar had set, the wedges were driven until the needles were relieved of their load. The needles were then removed and the niches in the

sides of the columns bricked up. No settlement occurred.

145–155 William Street

This building is a five-story brick structure, with column loads of about 150 tons each, and, with its completed underpinning, is shown in Plate No. 35. The brick columns, each resting on a small rectangular slab of concrete, were founded on sand.

Ground water was from one to two feet below the grade of the subway, so that underpinning pits could be sunk deep enough to render pile driving unnecessary. The design called for concrete piers about 25 feet deep and soil pressures of about 4 tons per square foot. The outside of the subway was the theoretical building line, which was 8 inches inside the face of the brick columns; thus the underpinning piers would form a masonry retaining wall for the subway excavation, the gaps between them being sheeted with horizontal sheeting as the excavation proceeded.

The first step was to place a concrete steel grillage so as to make the foundation of the building continuous. This was done by means of 18-inch longitudinal I-beams placed close to the columns and well dowelled in, with cross I-beams of different convenient sizes placed in niches cut for them in the brickwork, and the whole concreted, as shown on Plate No. 36.

Pit sinking was then started, three or four pits being sunk at a time, the ones under the center of the columns invariably being sunk last. The concrete in

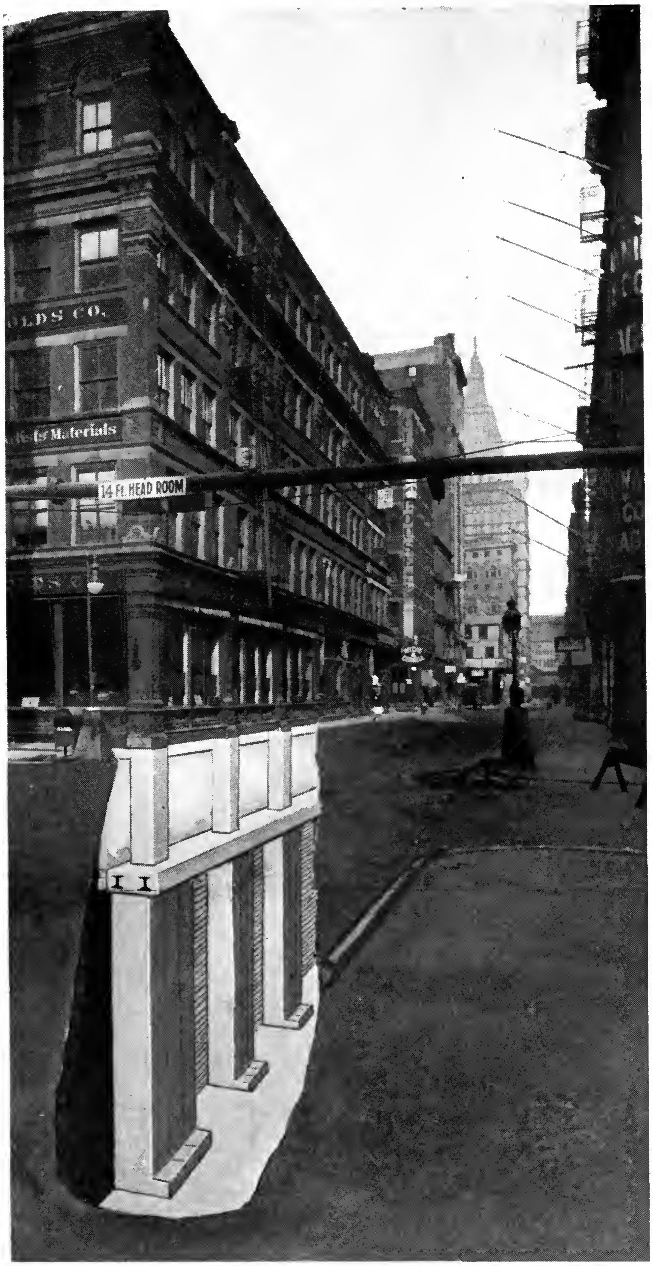

PLATE NO. 35. 145–155 William Street, Showing Columns, Grillage, Underpinning Piers, and Toe

Columns were first connected by a new grillage similar to that shown on Plates Nos. 18, 19, and 20. Piers sunk beneath this grillage were wedged up as per Plates Nos. 25 and 37.

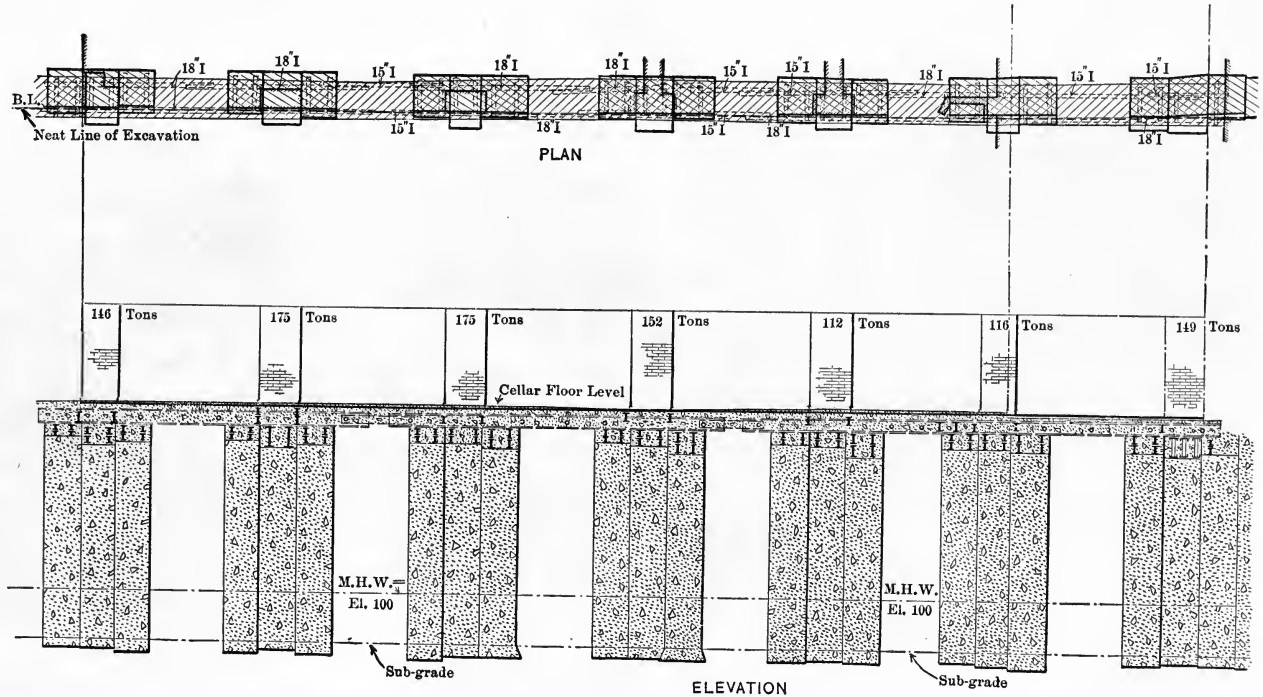

PLATE NO. 36. Showing Concrete-Steel Grillage, Underpinning Piers, and Wedging Beams to Convey Load of the Columns to the Piers. Typical for Moderate-Sized Buildings

the pits was left down about 2 feet below the grillage, and when set was wedged up and sealed with concrete and grout, pipes having been originally placed in the grillage for this purpose, as shown in Plate No. 37.

A toe, about 18 inches wide and 18 inches deep, reenforced with steel rods, was placed at the foot of each pit on the subway side, not only to give a larger bearing area, but also to counteract the overturning tendency of the high wall.

Bank of America

The Bank of America Building, on the northeast corner of Wall and William Streets, shown on Plate 38, is a nine-story office building, of the solid masonry construction that was used thirty years ago. The 3,000 tons of building on the William Street side, which had to be underpinned, were carried on six large brick columns, each with a load of 500 tons. The column bases, about 10 x 14 feet, rest on a continuous unreenforced concrete slab, about 2½ feet thick and 12 feet wide. The soil is a very fine-grained, compact sand and clay, ground water is 6 feet below, and grade 21 feet below, the bottom of the foundation; and the neat line of the subway excavation was the building line of the building.

The 14-inch steel concrete piles, which were jacked down in the usual way, were assigned a load of 30 tons in the design, and were founded on a stratum of hardpan about 29 feet below the foundation. Every pile,

PLATE NO. 37. Grillage and Underpinning Piers for 145–155 William Street.

The I-beam shown projecting through the column was used to help carry the load of the column to the steel-concrete grillage during the underpinning operations—after which it was removed

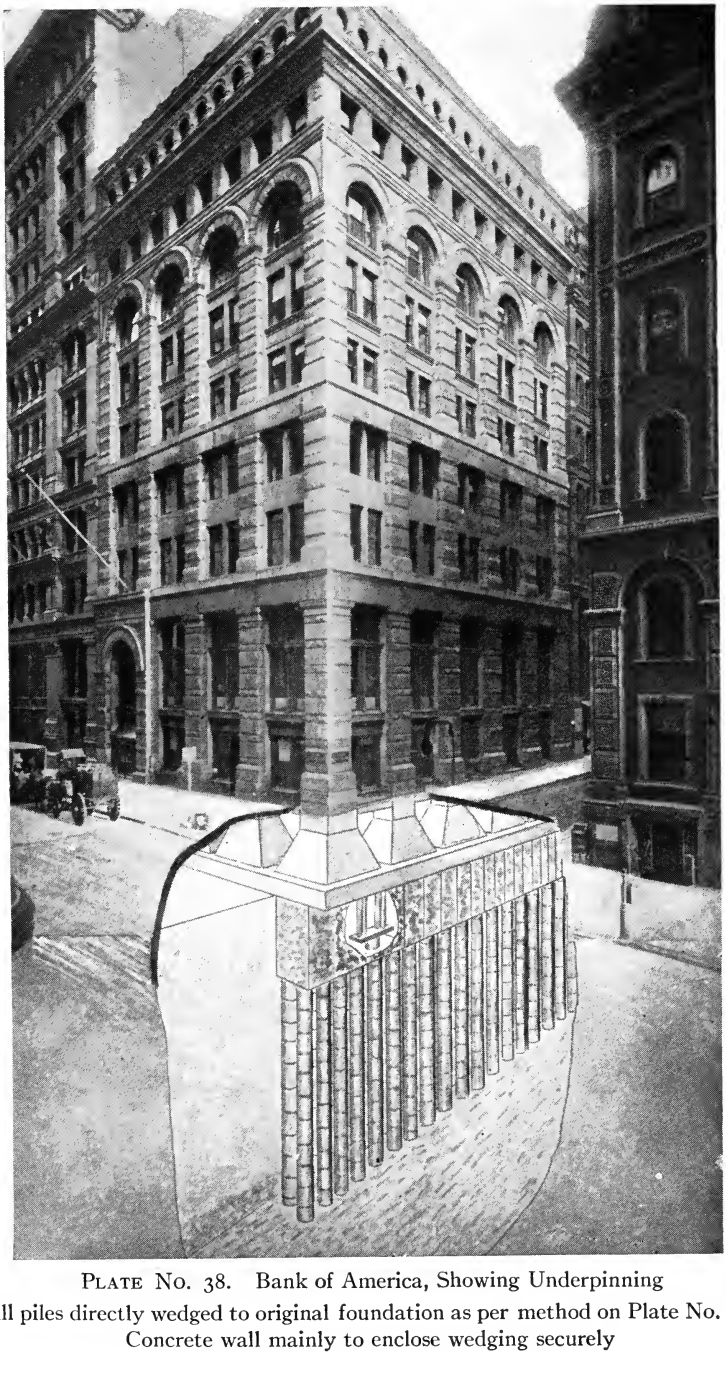

Plate No. 38. Bank of America, Showing Underpinning
All piles directly wedged to original foundation as per method on Plate No. 32. Concrete wall mainly to enclose wedging securely

after concreting, was tested to refusal with a load of 80 tons, and by means of the special pile cap, already described, was wedged up to the foundations with I-beams before the test load was removed. In some of the pits five piles were placed—this was because it was thought some piles might be buckled and lost—however, as this difficulty did not present itself the number was reduced to four, the number required by the design.

The first step was to concrete in six 15-inch I-beams, about 9 feet long, set X-wise between each pair of columns in niches cut for them in the brickwork, thus strengthening the foundations for the succeeding operations as shown in Plate 39. The 4-foot wide pits were then marked off and numbered, and pit-sinking started. They were sunk in sets of three or four, well distributed along the building, so as to make the settlement uniform and as small as possible, the ones between the columns being started first, because there the soil would be under least compression. Each set was completed before the next was started, and the order of sinking is given in the accompanying schedule:

Set 1	Pit	Nos.	5, 12, 20
" 2	"	"	8, 16
" 3	"	"	4, 13, 21
" 4	"	"	9, 17, 22
" 5	"	"	3, 10, 18, 23
" 6	"	"	2, 6, 11, 19
" 7	"	"	1, 7, 14
" 8	"	"	15

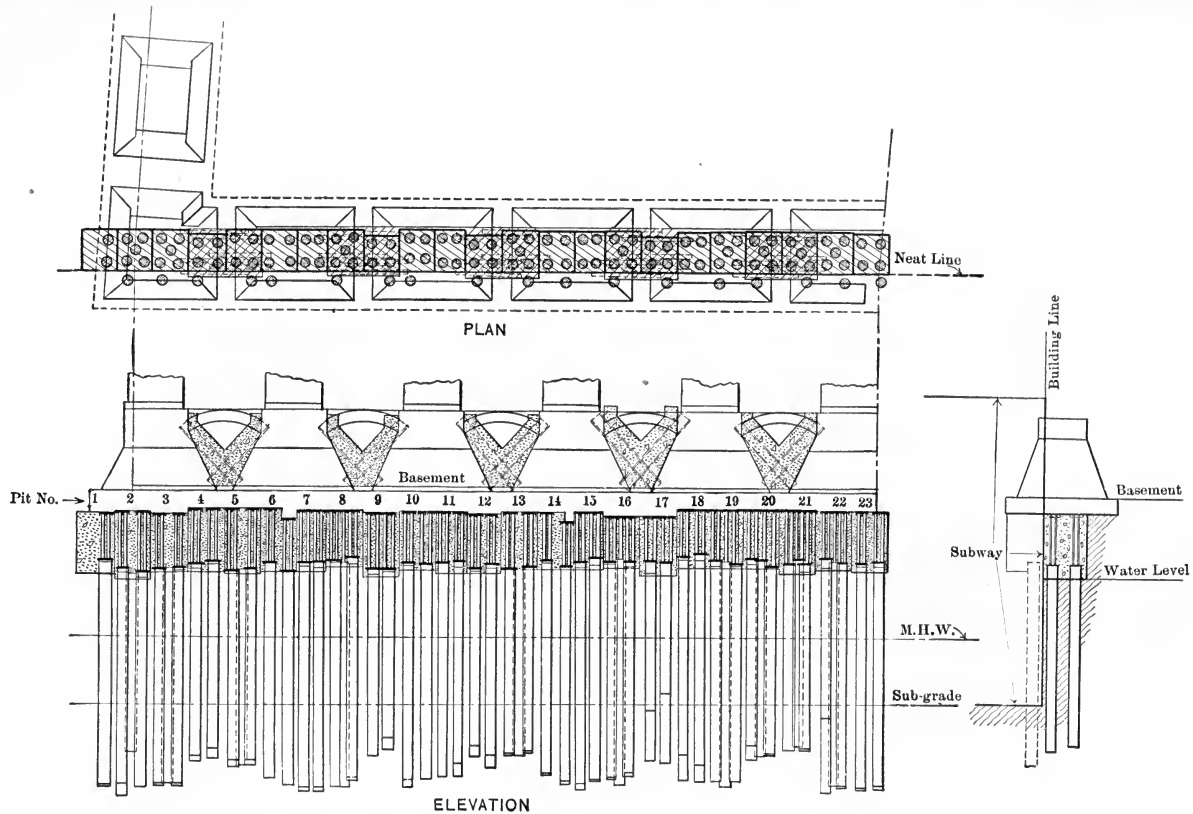

Plate No. 39. Plan of Underpinning of the Bank of America

All pits were similar, so only one will be described in detail. An approach pit down to water-level was dug, the rear of the pit being at the building line, and a

PLATE No. 40. Showing Brick Columns, Continuous Concrete Base, V-Shaped Concrete Enclosing Crossed 15″ I-Beams, and the Practically Completed Underpinning, Excavation for Subway Cut Started

temporary pile was jacked down and wedged up, thus replacing about 40 tons of the bearing area lost in the digging of the pit. The original soil load was about 3 tons to the square foot, about 25 square feet of soil was disturbed, so that probably 75 tons of bearing area were lost, which was compensated for by a slight settlement.

The pit was then extended 2 feet farther, two of

the permanent piles were then driven, one of which was wedged up and the pit then extended to its full width, 2½ feet more. The remaining two or three piles were then driven, all wedged up and the pit concreted, holes being drilled through the old foundation so that the pit could be grouted and a good contact secured between the pit concrete and the old foundations. Plate No. 40 shows a view of the foundations of this building when the underpinning was practically completed and the excavation of the soil in front of the building started. Plate 41 is another view showing the temporary piles and the overhang of the old foundations over the underpinning.

When the underpinning was completed, the wedging of the temporary piles was dismantled and the overhanging part of the old foundation was removed. The occupants of the building were hardly aware that operations were going on, as all the work was done below the street and outside the building. The settlement of the building was slight and very uniform, and there was absolutely no damage to the structure.

National City Bank

The National City Bank Building was formerly the New York Custom House, but after being taken over by the bank was remodelled, the interior being practically rebuilt and founded upon columns with wooden pile foundations. The exterior walls remained as a sort of ornamental shell, but were run up a few

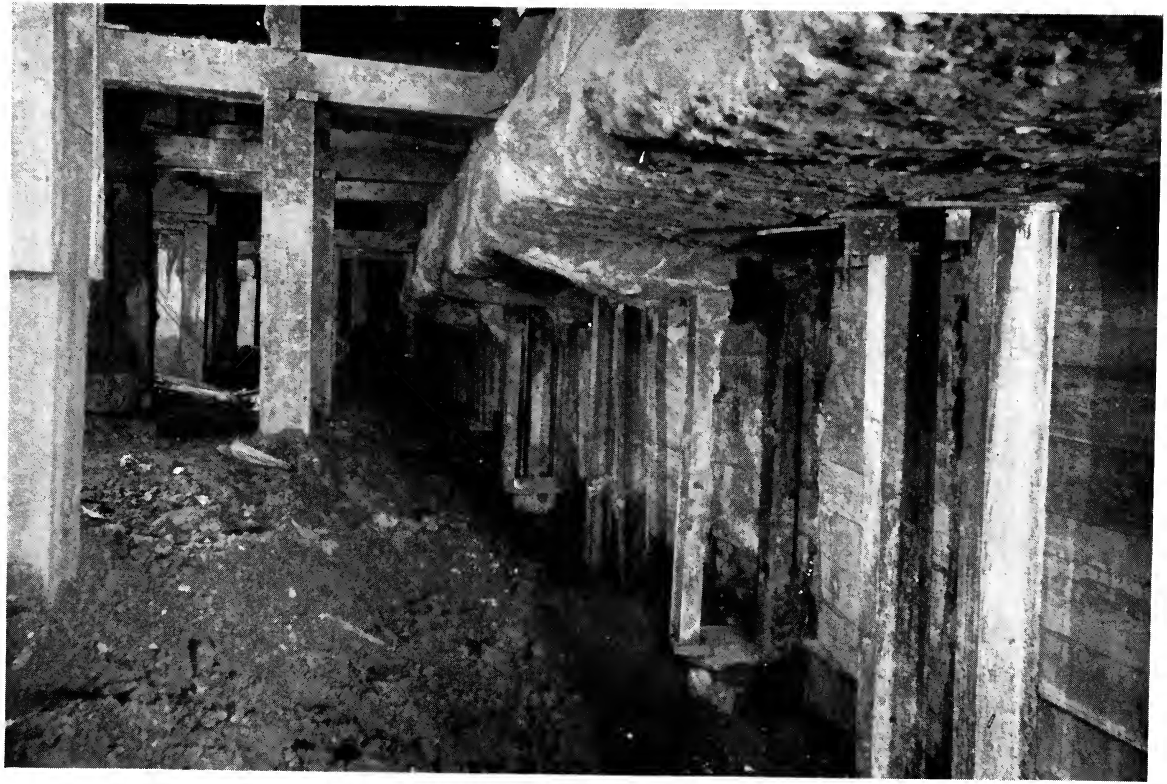

Plate No. 41. Photograph of Bank of America. Showing overhang of the old original spread foundations, concrete containing wedging and temporary piles after partial excavation. Completed excavation is about 15 feet deeper

stories higher. To protect the exterior wall from inside excavations around the inner perimeter of the walls during the building alteration, a row of heavy interlocking steel piling had been driven. The exterior walls and their footings are of granite resting upon the sand. The footing is about ten feet wide and the load per linear foot of wall about 30 tons.

The footings and walls appeared so massive that no attempt was made to reenforce them. A few 4-foot pits, spaced at wide intervals along the wall, were started and from them piles were driven to hard-pan, an average distance of about 27 feet and individually wedged against the huge granite blocks of the footing. The piles were so spaced that the average center line would be one foot from the center of loading of the wall. After the first series of pits were concreted and sealed, other sets were started until there was a continuous 4-foot wall of concrete under the entire front surrounding 181 piles, about one per running foot of wall. Most of the 4-foot pits were opened in two stages so as to minimize the loss of bearing area, that is, about two feet of their width was excavated and sheeted, the front row of piles driven, one of which was wedged up, and then the pit enlarged to the full width and the rear row of piles driven.

Owing to the importance of this building and the large interests involved, many tests were made as to the capacity of the 14-inch steel pile used. One test showed that the empty shell, only 7/64 inches thick,

held 90 tons applied with a hydraulic jack. Another pile, after reaching hard-pan under its first test load of 90 tons, settled only 1 inch and held its load absolutely without settlement for 60 minutes.

Although there was some apprehension with regard to this building, due to the fact that it had been extensively altered, and the shell-like nature of its exterior wall, but little settlement and very slight damage were manifest after the underpinning was completed. The underpinning took four months. To protect the material between the piles from flowing when the subway excavation opposite was carried to sub-grade, a row of light Lackawanna steel piling was driven just outside of subway structure. The National City Bank Building with its underpinning is shown on Plate No. 42.

Lord's Court Building

The Lord's Court Building is a nineteen-story, steel-skeleton structure at the corner of William Street and Exchange Place. For its foundation light spruce piles were closely driven over the entire plot (presumably to hard-pan), and on them a heavy platform of concrete, 4 feet 6 inches thick, was cast, the top of the piles being embedded in this platform about 6 inches. The piles, although in place about 25 years, were found to be in excellent condition; the ground water-level at the beginning of subway excavation was near the top of the piles.

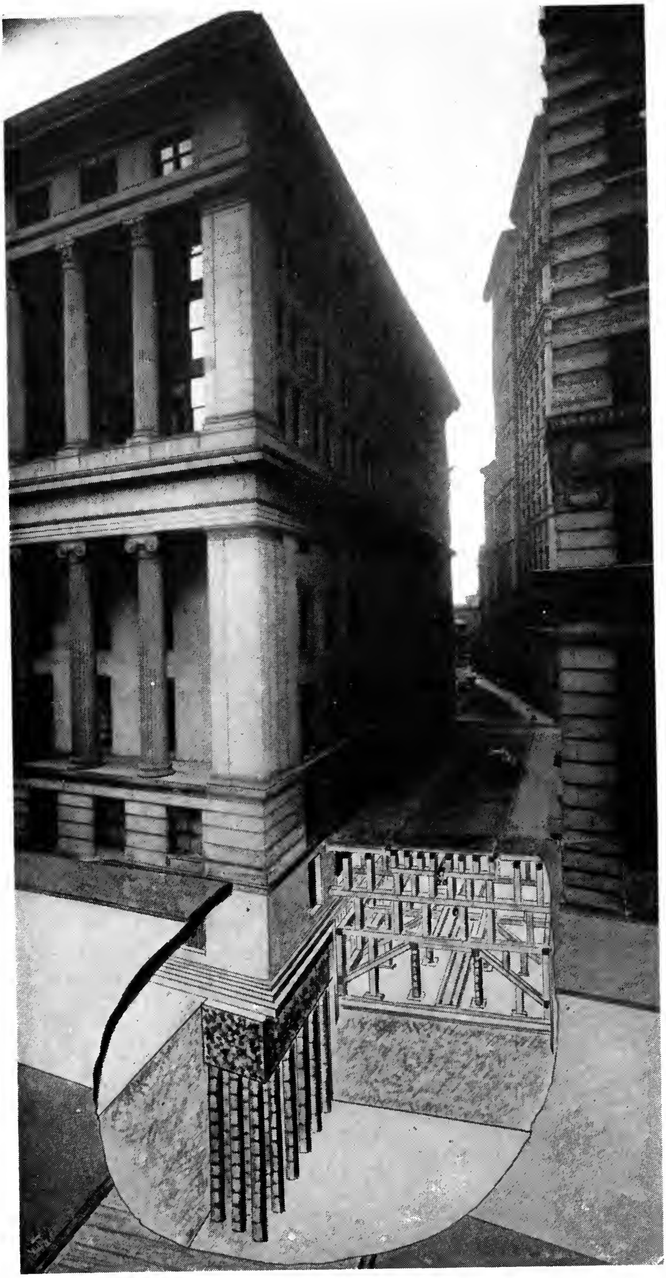

PLATE No. 42. National City Bank Building, Showing Its Underpinning and the Subway Cut

Piles extend to a layer of hard-pan 10 feet below sub-grade

Upon the concrete platform the piers supporting the building were founded. This platform with its supporting piles encroached from one foot to six feet upon the future subway structure.

The underpinning problem was to find a means of substituting new piles for the old ones, within the limits of the future subway, without endangering the building. As sub-grade was only about 8 feet below the bottom of the concrete platform, the subway cut was carefully excavated by the building, a protecting berm being left adjacent to it. From this berm temporary concrete-steel piles, about 5 feet on centers, were driven underneath the edge of the concrete platform, and wedged up to it. Next, a small strip of the upper portion of the berm was removed and the material between the wooden piles carefully excavated, so that by cutting one or two of them a 14-inch steel pile could be driven just back of the neat line of the subway structure. A steel pile was substituted for each two wooden piles removed. After a strip about 15 feet long was so underpinned, the rest of the berm was excavated, a form was set up just back of the water-proofing line of the subway, and a concrete face, about 24 inches thick, was cast directly against the bank and about the steel and wooden piles exposed. It was found that the material, although previous to draining a fine running sand, after being drained, could be cut down vertically. In this manner the entire front was passed safely without any settlement.

The supporting value of many of the wooden piles was recovered for the building by wedging between the face wall, resting upon the butts of the cut-off piles and the concrete platform of the building.

PLATE No. 43. Showing Substitution of 14″ Steel Concrete Piles for Old Wooden Ones Which Had to Be Removed in the Lord's Court Building

Plate No. 43 shows the underpinning operations.

The method of replacing wooden piles with those of concrete and steel is of wide application to cases where buildings are found to be resting on insufficient pile foundations and more especially where the top of the piles has decayed, due to lowering of the ground-water level. It would seem to be practicable to

replace the decaying wooden piles by permanent ones of steel and concrete. Each of the new piles, if properly tested and wedged, is easily as good as three wooden piles. A fair value of a wooden pile is 15 tons; 14″ steel-concrete pile, 45 tons.

The great advantage of the piles placed after the building is up is that the structure can be used as a reaction for driving, and, what is more important, for individually testing and loading the piles. Where piles are driven in the open there is no good way of testing them, and, moreover, those which are not on a firm foundation may not work at all, a few taking the load, unless the building settles sufficiently to throw the others into bearing which might be damaging to the structure. The underpinning of the Lord's Court was looked forward to with a great deal of concern because some of the piers were cracked for nearly the full height of the building, due probably to the cause outlined above. But the underpinning caused no further damage or settlement.

135 William Street

This large seventeen-story steel-skeleton office building, shown on Plate No. 40 with its underpinning on the southwest corner of William and Fulton Streets, was underpinned entirely from outside the building. The six columns on the William Street front which had to be underpinned were supported by a spread foundation consisting of a more

* PLATE NO. 44. Underpinning of 135 William Street

or less continuous unreenforced concrete mat. The foundation was only four feet above grade and water 1½ feet below grade. The outside of the subway excavation was the building line of the building, so that about 4½ feet of the old foundation that was left overhanging the underpinning had to be removed.

The first operation, after stripping the foundations, was to reenforce the foundation by means of six X-crossed 1¼-inch reenforcing rods concreted in the three gaps between columns. The 21 4 x 4-foot underpinning pits were then put in in sets of two, three

* Foundations were extended down a few feet by jacking down filled concrete piles into soft ground beneath and wedging to original foundation. Projections of foundation to left were later cut off.

and four pits at a time, care being taken to keep the pits opened, at the same time as widely separated as possible. All the pits were similar, so only one will be described.

Because of the quality of the soil encountered at water-level, its bearing power alone could not be relied on, so 14-inch steel-concrete piles were used in an unusual way. A 2-foot length was placed in the pit and concreted. The pile was then forced into the ground, more sections being added if necessary, until a reaction of 60 tons was obtained, and the pile then wedged up without releasing the applied test load.

An approach pit was put down so that the rear of the pit was at the building line, and usually a temporary pile was put in. Then the pit was extended, one pile driven and wedged up and the pit again extended; all piles driven, wedged up, and the pits concreted and grouted up. The approach pit was concreted up to sub-grade, reenforcing steel being first placed so that there was a toe which gave a larger bearing area and helped to overcome any overturning moment that there might be.

The Kuhn-Loeb Building

The Kuhn-Loeb Building is a modern twenty-one-story building, constructed in 1904, at Pine and William Streets, New York City, and with its underpinning is shown on Plate 45. Most of the columns are carried on I-beam grillages, consisting of an upper

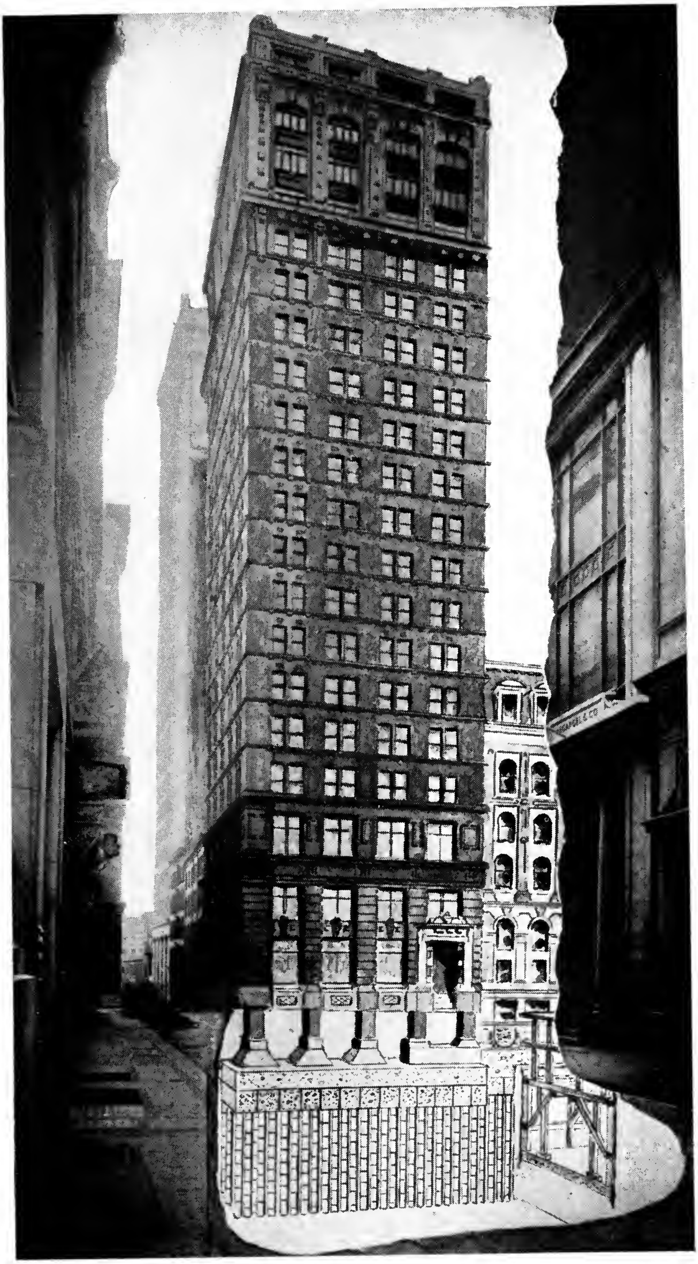

PLATE NO. 45. Kuhn-Loeb Building, Showing Its Underpinning
For details see Plate No. 42

layer of 20-inch I's, a lower layer of 15-inch I's resting on a 30-inch bed of concrete, which in turn was founded upon a fine sand just above water-level. The grillages of the exterior columns encroached about 5 feet on the street. The pair of columns adjacent to the Bank of New York was founded upon two large 5-foot 3-inch girders, in turn resting upon transverse I-beams founded upon a layer of concrete.

To put a subway through William Street it was necessary to cut off the encroaching foundations, remove the vaults and boiler foundations under the sidewalk; besides this, the owners feared that to underpin the building it would be necessary to occupy a large part of the interior of the basement, which would have seriously crippled the mechanical plant of the building. This plant, consisting of a large hydraulic elevator installation, boilers, dynamos, pumps, and even a refrigerating plant, was packed as closely as possible in the basement.

What further alarmed the owners was that the records showed, and of this the basement masonry and surrounding buildings gave ample evidence, that from the time the foundations were laid to the completion of the building a settlement of over two inches occurred. It was feared that any underpinning would further settle and seriously injure the building and its neighbor, the Bank of New York.

The Kuhn-Loeb Building became the storm-center of opposition to the William Street Subway, which

opposition defeated a projected subway through this street about ten years ago. However, the William Street line was an indispensable link in the dual-subway system, being the only feasible direct connection to Brooklyn for the new tubes under the East River, now being built for the Interborough system.

The property-owners engaged distinguished lawyers and engineers and most energetically opposed the City's application to the court to approve this line after the property-owners refused consent. The engineers for the property-owners built their case mainly on the difficulties of the underpinning of the Kuhn-Loeb Building, and the City retained experts to show the practicability of this underpinning, and convinced the referees to whom the matter was referred as to its feasibility.

The experts for the City submitted two methods: one by compressed air, proposed by Mr. F. L. Cranford; the other by piles, proposed by Messrs. Breuchard and Goldsborough. Mr. Cranford planned to place horizontal air-locks just outside the foundations and by their aid drive shafts through the water-bearing sand to hard-pan or rock, this shaft to be filled with concrete and to become supporting piers for the building. This method was expensive, being estimated at $90,000. The other method proposed was to sink 3-foot cylinders outside the foundations, these cylinders to support longitudinal girders, which in turn, by means of heavy suspender rods attached to flanges of the I-beam grillages, were to relieve the

foundations of a portion of their load so that it would be safe to drive piles directly below them. This method was estimated to cost $80,000.

The experts for the property-owners had difficulty in disputing either of the two methods outlined by the City's experts, and the referees stated they had confidence in the ability of the engineering profession to solve this problem when it came to it, but recognized the risks involved by requiring the City to assume primary responsibility for damage done to buildings by underpinning operations and the building of the William Street Subway, being the first and only time that the City has assumed such responsibility.

The contractor for the William Street Subway bid $32,000 for the underpinning of the Kuhn-Loeb Building, planning to use a simpler method than either of the methods proposed by the City before the referees.

Before starting operations the water-level was lowered by a sump and ditches sufficiently to allow headroom (4 feet) for the driving of piles. Meanwhile, the boilers were removed from the vault under the sidewalk and the foundations stripped. No space within the building was occupied for underpinning purposes, the machinery inside being protected by a hollow tile wall erected on the building line.

It was felt that by very careful work it would have been entirely feasible to underpin the grillages just as they stood, by gradually tunneling below the footages and securely wedging piles to make up for the

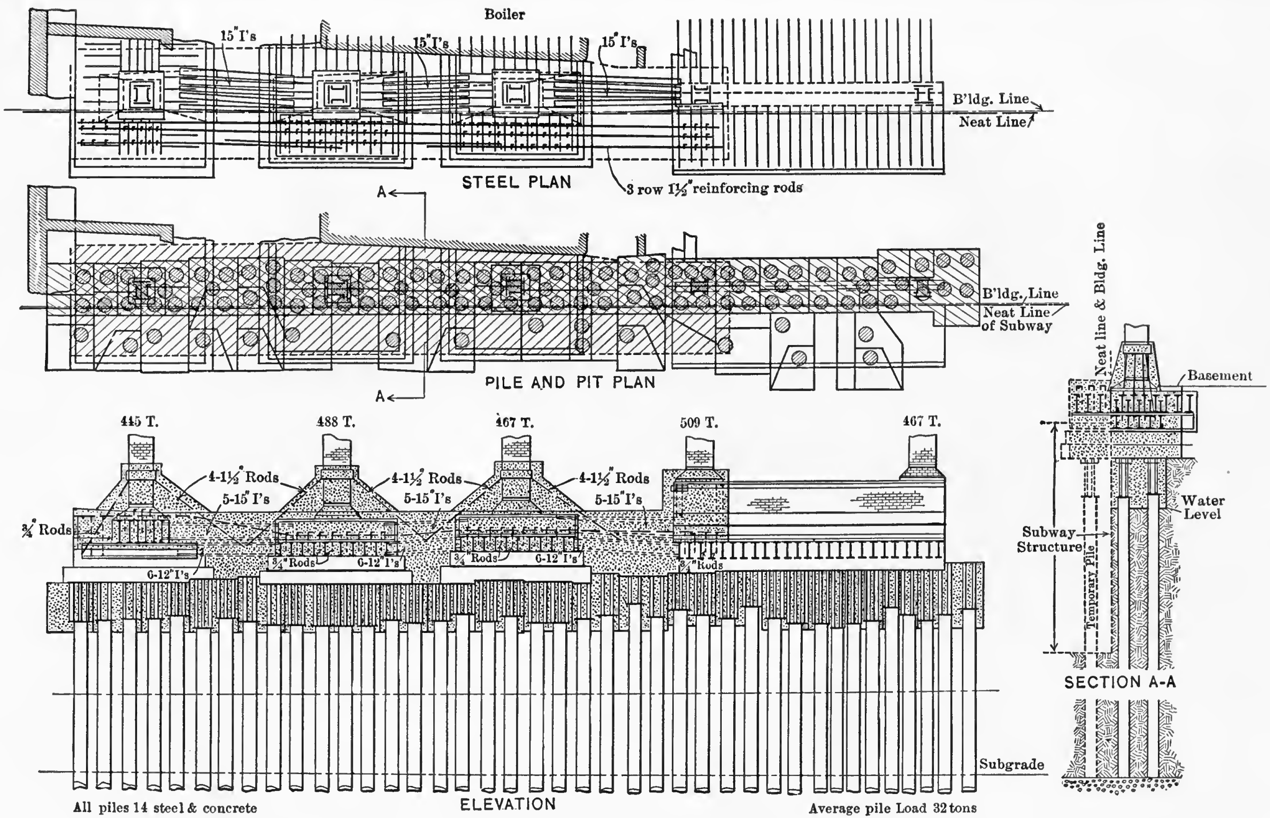

PLATE NO. 46. Plan of the Underpinning of the Kuhn-Loeb Building as Actually Carried Out
Piles extend 10 to 12 feet below sub-grade to a stratum of hard-pan and gravel

lost bearing area. However, to diminish the risk of underpinning and to enable a large measure of preliminary support to be obtained before actually going below the column footings a very heavy grillage was constructed. This in principle was merely the piecing out the gaps between the existing grillages, as shown on Plates Nos. 13, 14, and 15.

The next step was to open two pits between the old column footings and to wedge two preliminary or approach piles under the recently constructed grillage. These piles were loaded with about 40 tons apiece, using pile cap, jacks, and pair of I-beams described elsewhere. The first pits, only large enough for one pile apiece, were enlarged to provide for two permanent piles outside the excavation lines. One of these piles was wedged up and another enlargement provided for the back row of piles. After all piles had been wedged up, the pits were concreted in to form part of a permanent 4 ft. 6 in. wall just back of the building line.

The piles, shown on Plate 46, were driven so that the encroaching portion of the foundations was no longer needed and could be cut off. The whole constituted a system of tunneling, the footings being the roof, the pile props being good for about 90 tons each. It can be readily seen that even a twenty-one story building, with 500 tons' concentrations, can be readily carried by piles, there being ample room in any ordinary case for their driving. All the piles were driven

to a firm bearing on hard-pan at an average depth of 27 feet below the foundations, and each pile was very carefully tested and wedged while loaded, without releasing its test load of about 90 tons, though only assigned in the design a load of 32 tons.

Some very careful records made with the Berry strain gauge showed that after a pile was wedged a portion of its load was taken away by the neighboring piles as they were loaded, which would appear to indicate a slight actual lifting of the building. In fact, a very careful level record showed a very slight settlement of the building during the opening of the first pits, after which the building was stationary and even appeared to rise very slightly during underpinning operations. A piano-wire plumb line, 14 stories high, suspended to the side of the building and kept under observation during the underpinning operations, showed no movement whatever relative to the building. The building was absolutely undamaged. When we remember that this was the tallest building ever underpinned and the doleful predictions made, we may say that great progress in this class of work was demonstrated.

Underpinning Elevated Railroad Columns

Many elevated railroad columns have been underpinned in New York with no serious accidents and without inconvenience to traffic. Very many different methods have been used for temporarily carrying the

columns, with their ten-train loads, while the new foundations were being built, and the following one is the result of many trials and has been widely used by contractors.

A typical problem was to support two elevated

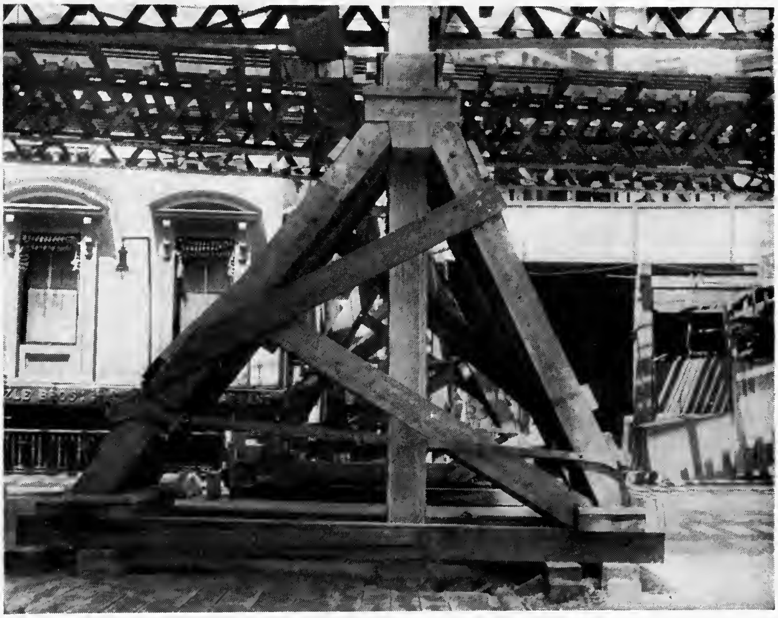

PLATE No. 47. Showing Method of Temporarily Carrying Elevated Railroad Columns

Tower shown is carried by concrete steel piles extending below sub-grade, as per Plate No. 48

columns, having loads of approximately 80 tons each, while the subway trench was dug to about 30 feet below curb, and the subway structure itself built, when the column could be placed on the subway roof which was designed for that purpose.

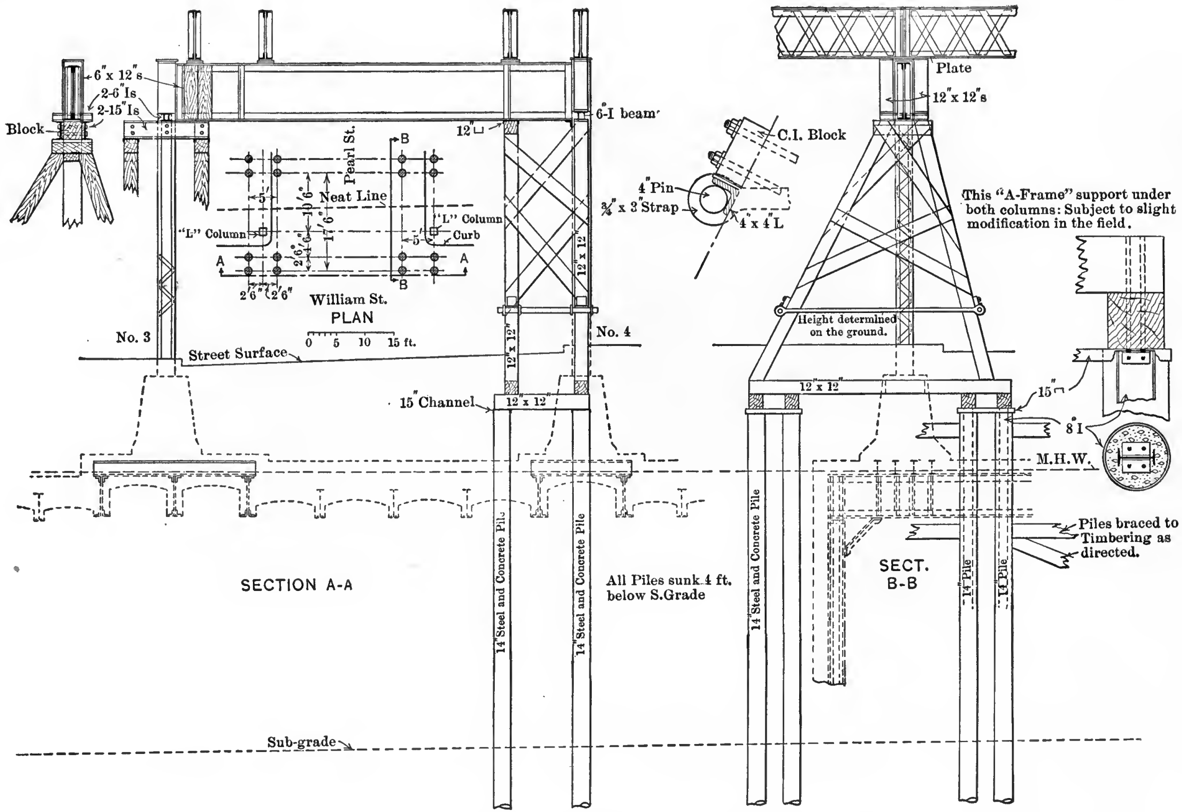

PLATE NO. 48. Plan of Underpinning Elevated Railroad Columns

The method used was to drive two groups of four 14-inch steel concrete piles for each column. This was necessary because water-level was about 10 feet below curb and it was impracticable to get pits down. These piles were driven about 5 feet below the sub-grade of the future excavation from the street surface in shallow pits, and were in such a position as not to touch the steel of the subway structure. When concreted, each group was capped with a small concrete cap, reenforced with ¼-inch reenforcing rods to tie the piles together. The piles which were loaded to about 10 tons each of live and dead loads carried the "A" frame which supported the column and elevated structure, the details of which are shown on the accompanying Plates Nos. 47 and 48.

One of the features of this frame is that the legs of the "A" are free to slide on the 12x12-inch sill, but are prevented from moving apart by the four ¾x3-inch iron straps which react through the 4-inch steel pin, which in turn is held in position by an iron block firmly bolted to the legs of the "A." When settlement occurs from time to time from any reason, the pins can be jacked down, and, by bringing the legs closer together, take up such settlement.

APPENDIX

UNDERPINNING IN ROCK

Rock excavation gives rise to underpinning problems differing somewhat from those described in previous chapters, but the differences are not quite enough to require extensive treatment. Buildings alongside of an excavation may be either on a cover of earth above the rock or wholly or partly on the ledge. The worst conditions exist where the building is founded on rock tending to slide into the excavation.

If a building is founded on rock and it is felt that this rock is insecure, then new piers have to be carried down to sub-grade or until a secure rock stratum is reached. The process is simple, although tedious, and in some cases costly. Small shafts are sunk directly below the building to a proper depth in the rock and filled with concrete upon which the building is wedged. The great advantages of underpinning a building to rock is that no pier will suffer any settlement and can carry a very heavy load, a 4 x 4-foot pier being good for at least 400 tons, while on ordinary earth it would be good for only 80 tons. It is, therefore, advantageous in rock to strengthen the foundation with a heavy grillage so as to take advantage of the great bearing value of rock and to save expense and time by sinking only a few shafts.

The largest building known to the authors founded upon rock and requiring underpinning is the Metropolitan Opera House, a subway passing close to both the Broadway and Seventh Avenue fronts. On the Seventh Avenue side the rock was of a treacherous character. The main cut was driven by the adjacent wall of brick, leaving several feet of rock berm adjacent to the building. Then narrow shafts were sunk underneath this wall, which readily bridged over small openings. Each shaft was filled with concrete and wedged to the brick wall till a new continuous wall approximately to sub-grade was formed, after which it was safe to complete the excavation. The Broadway side of the building was founded upon huge isolated brick piers. At the side of each pier and a few feet below, the rock was excavated in shallow shafts and concrete placed so as to form an arch spanning a shaft sunk directly below the center of each pier to subgrade. Later the shaft was filled with concrete, forming a pier to which the footing was wedged.

Where the side of a rock cut is ragged and subject to disintegration or slides so as to endanger buildings alongside, a concrete wall cast directly against the face of the rock is often very effective and economical. Such walls are much more readily braced than the usual rock face and often give warning of an imminent slide by the cracks which would form and which would be readily discernible.

SPECIAL ARRANGEMENT OF PIT BOARDS

In some instances, where mealy running sand or where there is a small amount of water encountered, openings may be left between successive pit boards when horizontal sheeting is used. These openings may be formed in several different ways, such as boring holes, chopping slots in the boards, separating boards by small wooden spacers nailed on the tops or sides of the horizontal boards. This permits the packing of sand, hay, straw, mortar, moss, or other material to prevent the loss of ground.

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